Vegetation Restoration Success in Water Line Disturbance and Experimental Plots at Wind Cave National Park: Final Report

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FINAL REPORT
Natural Resources Preservation Program
PROJECT NUMBER: 04-02 2.17
FISCAL YEAR: 2006
DATE: August 30, 2007

FINAL REPORT

NRPP FUNDING PROGRAM and YEAR: BRD-Research, 2006

NATIONAL PARK SERVICE REGION: Midwest

TITLE: Vegetation Restoration Success in Water Line Disturbance and Experimental Plots at Wind Cave National Park

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Table of Contents

INTRODUCTION

The Black Hills Community Inventory Report (Marriot et al. 1999) rated Wind Cave National Park as exemplary for its large amounts of high quality vegetation with natural processes in place. Thus, when necessary maintenance and improvement activities disturb the ground and vegetation, it is a high priority to re-establish native vegetation as quickly as possible in order to preserve this integrity. This is particularly important in the semi-arid environment characteristic of Wind Cave NP, where rates of natural recovery by native species are generally slow, and undesirable species often invade such disturbed areas. Until recently, revegetation projects at Wind Cave NP used a seed mix recommended by the U.S. Department of Agriculture's Natural Resource Conservation Service (NRCS). This seed mix consists of two cool-season grasses (western wheatgrass, *Pascopyrum smithii*, and green needlegrass, *Nassella viridula*) and three warm-season grasses (sideoats grama, *Bouteloua curtipendula*, blue grama, *Bouteloua gracilis*, and buffalograss, *Buchloë dactyloides*[1]). All of these species are native to Wind Cave NP, but the seeds for revegetation projects come from commercial suppliers. Questions about the success of plantings using this mix, as well as other questions about alternatives for revegetation of disturbed areas at Wind Cave NP form the foundation of this study.

Casual observations suggested that plantings using the NRCS mixture did not establish quickly (M. Curtin, Wind Cave NP, pers. comm.). Instead, recruitment of species from the prairies surrounding disturbed lands seemed to contribute significantly more to the vegetation of disturbed areas than did the seeded species. It is not uncommon for revegetation projects involving native prairie species to take three or more years to appear successful (e.g., Banerjee et al. 2006, Piper et al. 2007.) This is often explained by the fact that many native prairie grasses allocate much of their resources early in life to establishing extensive root systems instead of putting on aboveground biomass (Schramm 1990). Thus, planted species may establish but not be very noticeable, especially in the first couple of years following planting. During the time of initial establishment, fast-growing, undesired species (weeds) can be much more visible than the planted species. If this is the case, time may solve the problem as long as undesirable species are kept under control. However, controlling undesirable weedy or invasive species until the planted

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[1] Species nomenclature throughout this report follows the Integrated Taxonomic Information System (http://www.itis.usda.gov/ accessed May 2007). Common names for all species mentioned in the report are given in Appendix 1.

species become large enough to out-compete the other species is not always possible. Quantitative information on the success of planted species and other species in revegetated areas through time has not been collected at Wind Cave NP, leaving these anecdotal impressions untested.

Questions regarding the merits of fall planting to spring planting also exist. Each of these seasons has its advantages and disadvantages. Fall plantings provide conditions more similar to the natural regeneration process than do spring plantings because fall-planted seeds experience the variations in temperature, light, and moisture that often are necessary to stimulate germination. However, because of the longer time between planting and germination, there is a greater chance in fall plantings that seeds will be lost to wind or eaten by animals (e.g., Howe et al. 2002), particularly if there is little snow cover in the intervening winter.

Also, although the grasses in the NRCS mix are matrix species in the park's grasslands, the diversity of the recommended mix is quite low compared to native vegetation. Coppock et al. (1983) found 12 species of graminoids, 18 species of forbs, and 4 species of shrubs in plots totaling just 4 m^2 scattered throughout a 0.4 ha area of undisturbed prairie in Pringle Valley at Wind Cave NP. Symstad et al. (2006) found 44-63 native species in plots totaling 10 m^2 within 0.1 ha grassland sites in four different areas of Wind Cave NP. Greater diversity in a seed mix generally increases the chances that at least one of the species planted will be successful in filling the open ground. In addition, experiments manipulating plant diversity suggest that greater diversity in prairie plantings decreases the chances of invasion by undesirable species (Naeem et al. 2000; Kennedy et al. 2002; Biondini 2007) and increases native species richness and the proportion of plant cover comprised of desirable species (Piper et al. 2007).

Increasing the diversity of revegetation mixes raises the questions of which additional species to use and how to obtain their seeds. Composition of plantings designed to mimic native vegetation are obviously determined by the species that occur in the area, but they are also constrained by seed availability and influenced by the expected success of individual species in the planting.

Seed availability, particularly for native forb species, can be low and/or the cost of these seeds prohibitively expensive. In addition, park staff would prefer that seeds for revegetation projects come from within the park or the near vicinity rather than from commercial origins. Local seed sources are generally recommended for restoration in natural settings because they are presumably better adapted to local environmental conditions (Falk et al. 2006). This is important not only for the first generation of plants in a revegetation project, but also in the long term. Natural populations may have greater genetic diversity, and therefore adaptability, than commercially grown seeds (Stockwell et al. 2003), particularly when the commercially grown seeds are "improved" varieties. Breeding between varieties from different conditions and the park's native populations may reduce the fitness of seeds produced by the local populations (Rieseberg 1991; Hamilton 2001). Consequently, information on the potential for and costs involved with using locally collected seeds was needed.

Predicting the success of individual species or mixes of species, particularly of those not commonly used in plantings, is extremely difficult. One tool that might be useful is the coefficient of conservatism (C-value) of individual species. This coefficient is a numerical index indicating the likelihood that a species will occur in highly disturbed conditions within a specific geographic area (Swink and Wilhelm 1994, Northern Great Plains Floristic Quality Assessment Panel 2001). Therefore, it is an indicator of species' sensitivity to disturbance. In this rating system, native species that typically occur in disturbed areas receive low C-values (0-1), and native species that typically occur in undisturbed, high-quality natural areas receive high C-values (9-10). For example, curly-cup gumweed (*Grindelia squarrosa*) has a C-value of 1; big bluestem (*Andropogon gerardii*) has a C-value of 5; and leadplant (*Amorpha canescens*) has a C-value of 9. The five grass species comprising the seed mix used in recent revegetation projects at Wind Cave NP have C-values in the middle of the conservatism range (4-7). Standard prairie planting practices in the tallgrass prairie region include planting native species with low C-values in order to keep undesirable weeds down while slower-growing planted species (like the grasses in the current seed mix) become established (Packard and Mutel 1997). The theory behind this practice is that the more disturbance-adapted species will eventually be out-competed by later successional, more conservative species (i.e., with higher C-values) if disturbance does not recur. However, some have suggested that many seed mixes are over-dominated by fast-growing, less conservative species, which create a dense canopy or litter layer that the more conservative species cannot penetrate (Weber 1999). Although soil disturbances are generally thought of as providing habitat for early successional species, later successional species can also take advantage of the light and soil resources released by soil disturbance (Rogers and Hartnett 2001). Thus, planting just the more conservative species in the bare soil following construction may yield vegetation that more closely resembles the native vegetation in a shorter time, provided that unplanted, undesirable species do not gain control of the site. These concepts were tested in this project.

I report here on the results of a two-part study over a three-year period (2004-2006) addressing these issues. **Part 1** assesses the success of revegetation of the area disturbed in the 2000-2001 “water line” construction project in relation to nearby undisturbed areas. **Part 2** experimentally compares alternative mixes of species, planting seasons, and local- vs. commercial-origin seeds for planting in disturbed areas.

Analysis and interpretation of data collected from Part 1 yield a quantitative assessment of the revegetation success in a recent construction project. In addition, this part of the project evaluates individual species’ abundance in the revegetation project to suggest native species appropriate for future revegetation projects – i.e., those species who seem to thrive in this disturbed condition. In Part 2, analysis and interpretation of data from experimental plots planted with nine different species mixes, in two different seasons, builds upon the results of the water line revegetation project. Comparison of mixes as a whole is used to evaluate different planting strategies, whereas evaluation of individual species’ success in the plantings provides information useful for refining mixtures for future use.

METHODS:

Study Site

Wind Cave NP is located on the southeastern edge of the Black Hills in southwestern South Dakota. The Black Hills are an isolated extension of the Rocky Mountains with vegetation comprised of elements from sagebrush steppe, western coniferous forests, eastern and northern deciduous forests, and mixed and short-grass prairie. The park has a full complement of native large herbivores, including American bison (*Bos bison*), pronghorn (*Antilocapra americana*), elk (*Cervus elaphus*), white-tailed deer (*Odocoeileus virignianus*), and mule deer (*O. hemionus*), and numerous small herbivorous and granivorous mammals, all of which had free access to most areas used in this study. Although black-tailed prairie dogs (*Cynomys ludovicianus*) are abundant in the park, none of the areas in this study fell in prairie dog colonies.

The climate is continental, with hot summers (July mean daily maximum 31° C) and cool winters (January mean daily minimum -12° C). Average annual precipitation is 44 cm, with the wettest period being May-July, when precipitation usually occurs as rain during thunderstorms.

Part 1: Assessing the Water Line Revegetation Project

The area assessed for revegetation success at Wind Cave NP was in the 2000-2001 "water line" project. This construction project buried a water pipeline from two wells to the visitor center. The area disturbed by this project, which is a long (~5.6 km), crooked line 2-4 m wide, was still quite visible at the outset of this study in spring 2004 (Figure 1). The line runs through a variety of vegetation and soil types. Areas disturbed by this construction were planted at two different times. The shorter segment, extending approximately northwest from the visitor center, was planted in the fall of 2000, and is within a fence that excludes bison. The longer segment, extending approximately east from the visitor center, was planted in the spring of 2001 and is accessible by all the park's large herbivores. Seeds for both plantings were from a commercial source, but records of their origin were not kept. Planting was done via hydroseeding, in which seeds are combined with a sluice of degradable mulch and sprayed on the soil's surface.

<u>Vegetation Measurements</u>

Vegetation composition, cover, and diversity were measured in 200 1 m x 0.5 m plots placed at 10 m intervals in 20 transects. Each transect had ten plots, and transects and plots were paired so that one transect was in the approximate center of the area disturbed by the burial of the water pipeline and the second transect was in vegetation undisturbed by the construction ("reference vegetation"), parallel to and 10 m from the plots in the disturbed area. Eight and two of these transect pairs were located in the longer and shorter water line segments, respectively, in proportion to the area covered by each of these segments. The start of each transect pair was randomly chosen within these segments, with the restriction that transects could not overlap.

The density of the five planted species in the disturbed area was measured as the number of "individuals" and cover of each species in each disturbed plot. Counts were done by mapping the location of each individual on a grid representing the plot, which was delineated by a portable plot frame subdivided into a grid of 10 x 10 cm squares. An individual was defined as a shoot or group of shoots sharing the same roots. Thus, for the bunch grasses (all but *P. smithii*) an individual was a clump of shoots. For *P. smithii*, individuals were generally single shoots because the rhizomatous growth form of *P. smithii* made it impossible to distinguish individuals that originated from a single seed. Foliar cover of each species was visually estimated to the nearest 1%.

Plant community measurements consisted of visual estimates of the foliar cover of each species in the plot. In addition, the plot area not covered by green (live) foliage was categorized as litter, bare soil, or rock, and the area covered by each of these categories, as a percentage of the plot, was estimated. The sum of the cover of all these (plants and non-plants) was made to equal 100 unless there was significant layering (e.g., shrub foliage covering grass foliage), which was rare. In the first year of data collection (2004), cover estimates were done twice during the growing season (June 7-28 and August 4-19). In the following years, cover estimates were done only once (July 7-28, 2005; July 24-August 7, 2006) because of time constraints. Except where noted, analyses using 2004 data used August values, as these are more consistent with the later sampling times of the following years.

Data Analysis

For each planted species, and only in the disturbed plots, the number of individuals per plot and the species' cover were compared between the fall-planted plots (transects 9-10) and the spring-planted plots (transects 1-8) and through time with a repeated measures analysis of variance (RMANOVA) using the MIXED procedure in SAS (SAS Institute Inc. 2004). Plots were considered subsamples within transects; thus, transects were the sample units.

RMANOVA using the MIXED procedure was used to compare aggregate community measures and ground cover characteristics between disturbed and reference plots through time. Each pair of transects was treated as a random block and plots within paired transects were paired subsamples. Where necessary, data were transformed to better fit the normality assumption of RMANOVA. Jaccard's similarity index was calculated for species composition in each transect pair in each year, and ANOVA was used to compare this index over the three years of data collection. When ANOVA effects were significant ($P < 0.05$), comparisons of least-squares means were used to evaluate differences between disturbed and reference vegetation and/or among sampling years.

The blocked multi-response permutation procedure (MRBP) in PC-ORD (McCune and Mefford 1999) was used to test for differences between the reference and disturbed vegetation based on the importance value[1] of species in the appropriate (disturbed/reference) transect of each transect pair. Principal Components Analysis (PCA) was used to qualitatively discern species that contributed to the difference in composition between disturbed and reference vegetation and to evaluate changes in composition from 2004 to 2006. Differences in the rate of change in composition from 2004 to 2006 were compared between the reference and disturbed vegetation using the following method: (1) vector length between the scores on the first two PCA axes in the second PCA described above was calculated for each transect-plot type pair; (2) a paired t-test was used to determine whether the vector length was different between reference and disturbed transects (McCune and Grace 2002). PCA and its assumed linear response was acceptable for these data sets because gradient lengths in detrended correspondence analysis (DCA) did not exceed 3.0 SD (ter Braak 1995).

Indicator species analysis (Dufrêne and Legendre 1997) in PC-ORD was used to quantitatively test for the adherence of species to disturbed or reference vegetation. This procedure combines species frequency and abundance information into a value representing the degree to which that species is faithful and exclusive to a group (disturbed or reference vegetation, in this analysis). Indicator values are tested for statistical significance using a Monte Carlo method. Only species that occurred in at least 5% of the plots in at least one year of the study (49 species) were used in ordinations and indicator species analysis.

Part 2: Comparing Seed Mixes in Experimental Plots

Forty-four species were used in the experiment comparing seed mixes (Appendix 1). A complete description of seed collection and handling methods, species composition of mixes, experimental design, and planting methods was provided in a previous report (Symstad 2006). Therefore, these items are only summarily described here. Two sources of seed were used, depending on the experimental treatment (see next section). "Locally collected" seed was hand-harvested from natural populations within Wind Cave NP or in its near vicinity. Commercially

[1] Importance value is calculated for a species within a transect as the sum of its relative frequency and its relative cover.

grown seed was purchased from Foothills Seed, Inc. (Sturgis, SD), using varieties recommended for the vicinity of Wind Cave NP.

Seed viability was tested by standard methods (South Dakota State University Seed Testing Laboratory, Brookings, South Dakota) for 25 of the locally collected species. Sufficient quantity of the 19 remaining species was not available for viability testing. Viability rates of the commercially-grown species were provided by the supplier. Because viability data were not available for all species, this information was used only in interpretation of results, not to adjust seed planting rates.

<u>Seed Mixes and Experimental Design</u>

Five main treatments were planted in the experiment. The composition of the first three treatments was determined by species' C-values (Low = 0-5, High = 5-9, Mixed = 0-9) and the seeds used were locally collected. Within each of these three treatments, two distinct mixes (designated L1, L2 for low C-value, H1, H2 for high C-value, and M1, M2 for mixed C-value in Table 1) were compiled so that the effect of different species composition within C-value treatment could be assessed. The fourth main treatment consisted of four of the five grass species used in previous plantings (*P. smithii*, *N. viridula*, *B. curtipendula*, and *B. gracilis*) and *Schizachyrium scoparium* as a replacement for *B. dactyloides*. Within this treatment, two separate mixes were distinguished by the origin of their seeds, locally collected or commercial (designated PML and PMC for previous mix-local and previous mix-commercial). The fifth treatment was a control (designated C), in which no seeds were planted. These treatments are summarized in Table 1.

Plots were established in a 65 m x 20 m, flat area at the park's "Mixing Circle". The vegetation in this area was generally weedy and patchy due to previous disturbances, and various materials had been stored on it for years. In late November 2004, these materials were removed and the area was graded to break up established vegetation and loosen the soil. Ten blocks of nine 3 m x 3 m plots were demarcated. Half of the blocks were randomly assigned to be planted in the fall, and the remaining half to be planted in the spring. Within each block, seed mixes were randomly assigned to the plots, with each block having all nine seed mixes. Therefore, there were five replicates for each seed mix x planting season combination,.

The number of seeds planted in each 3 m x 3 m plot was held constant at 4,800. This is approximately double the NRCS recommended rate of 270 seeds/m^2. For L, H, and M mixes, three species were planted at 750 seeds per plot, three species were planted at 450 seeds per plot, and eight species were planted at 150 seeds per plot. In all but one of these mixes (L1), two of the species seeded at the highest rate were grasses. These values were chosen to represent dominant, subdominant, and occasional species, constrained somewhat by availability of seed. For PM mixes, all species except *P. smithii* were planted at 1137 seeds per plot; *P. smithii* was planted at 252 seeds per plot because of low seed availability for the locally collected mix.

Seed Handling and Planting

Locally collected seeds were harvested by hand from throughout the park as each species ripened in 2004. Three species were collected from natural populations within 80 km of the park because of difficulties finding viable seeds within the park. Between collection and processing, seeds were stored in paper bags in a cool, dark place. After all seeds were collected, all collections were combined and mixed thoroughly by species. The number of fully-formed seeds in five small subsamples from each species was counted to estimate the seed number per unit mass of seed. Using these values, the appropriate mass of seed of each species was measured for each plot, and most species for a plot combined with an approximately equal volume of damp sand to aid in spreading during the planting process. Species requiring light for germination (*Artemisia frigida, Artemisia ludoviciana, G. squarrosa,* and *Monarda fistulosa*) were kept separate from those combined with the sand. Legume species were scarified with sand paper after weighing and prior to being mixed with other species in the sand. All seeds were planted by hand broadcasting. Seeds in the sand were raked into the plot's soil, and then light-requiring seeds were sprinkled on top. The fall planting was done on 13 December 2004 and the spring planting on 4 May 2005.

Plot Maintenance and Monitoring

Plots were maintained and data collected in 2005 and 2006. Growing-season natural rainfall was monitored at the experimental site May-September in both years. The planted area was watered as needed from late May to late September 2005 to keep seedlings from desiccating. This supplemental watering added approximately 6.4 cm to 33.6 cm of natural growing-season rainfall. Time constraints and equipment failure led to less water being applied in 2006; approximately 3.0 cm were added late May-mid August to 17.6 cm of growing-season natural rainfall. Average May-September rainfall for the park is 29.2 cm. *Cirsium arvense* and *Onopordum acanthium*, aggressive exotic species, were clipped prior to flowering throughout the 2005 and 2006 growing seasons from plots in which they were abundant. These clippings were removed from the plot.

Vegetation in the experimental plots was measured twice during each growing season, once in mid-May to early July and again in August and September. The central 2 m x 2 m square of each plot was sampled with four 1 m x 0.5 m subplots arranged in a checkerboard pattern. Within each of these subplots, cover values for each plant species was visually estimated as in the waterline part of the project. In 2005, seedlings of all species planted in the particular plot were mapped and counted, and the total cover of each species' seedlings estimated. In 2006, this procedure was continued and supplemented in two ways. First, surviving seedlings from 2005 were mapped and counted. Second, seedlings of species planted anywhere in the experiment were mapped and counted in the control plots (Mix C). The latter was done because data from 2005 showed that many seedlings of species planted in the experiment occurred in plots in which they were not planted. These seedling counts in the control treatment serve as a measure of background soil seed levels, with the acknowledgement that this background measure is not ideal because equivalent data for 2005 were not collected.

Data Analysis

Data were compiled at the plot level and at the species level. Plot level data are aggregate measures of the plant community, such as native species richness, total exotic species cover, and seedling number as a proportion of the seeds planted in the plot. Species level data were compiled for species over all mixes in which they occurred and include measures of success such as seedling number as a proportion of seeds planted in plots ("adjusted seedling number") and mortality rates over different time periods. In all cases, data from subplots were combined into a plot value before any other compilation so that plot is the sample unit.

For cover data, the maximum value of the two sampling times for a subplot was used for each species. This was done to account for the variability in maximum cover time among the species. For seedling counts, the total number of seedlings occurring in the sampled portion of the plot in a year was used for most analyses. Seedlings surviving from the first to the second round were counted only once. Mortality rate calculations (within seasons and overwinter mortality) used seedling numbers from each sampling period separately. Natural seedbank occurrences were differentiated from seed mix treatments by contrasting seedling numbers in planted plots to control plots in the same block. Three planted species (*Pascopyrum smithii*, *Rosa arkansana,* and *Symphoricarpos occidentalis*) were not included in any analyses using seedling counts because of difficulties distinguishing between seedlings and vegetative sprouts from residual vegetation.

Effects of planting season, seed mix, year of data collection, and their interactions on aggregate plant community measures were evaluated with a repeated-measures split-plot ANOVA model using the MIXED procedure in SAS, followed by comparisons of least-squares means when effects were significant (SAS Institute Inc. 2004). Block was a random factor. Effects of species identity and species x planting season interaction on adjusted seedling number, seedling cover, and mortality were evaluated using the MIXED procedure in SAS. Species-level responses were analyzed separately for 2005 and 2006, and species were generally not separated by seed mix. In order to compare the success of locally collected and commercially grown grass seed, adjusted seedling number and seedling cover of individual species was compared in separate (one for each species) ANOVAs evaluating the effects of seed mix (PML and PMC only) and the interaction between seed mix and planting season.

Proportions were arcsine-square root transformed for analysis, and other values were log-transformed if necessary to improve the normality of the dataset. Unless otherwise noted, statistical analyses for this part of the study use $\alpha = 0.10$ because of high variance among replicates.

RESULTS:

Part 1: Assessing the Water Line Revegetation Project

Planting Season

There were four times as many *B. gracilis* individuals ($P = 0.02$) in spring-planted areas than in fall-planted areas. Although there was no difference ($P > 0.10$) in density between planting seasons for any other planted species, there was a trend for greater numbers of individuals in the spring-planted areas (Table 2). Density of each planted species was similar over the three years of data collection ($F_{2, 16} \leq 2.50$, $P \geq 0.11$), and there was no interaction effect of season and year for any species ($F_{2, 16} \leq 0.85$, $P \geq 0.45$). Cover of the planted species in the disturbed area varied slightly more than density among planting seasons and through time. *Bouteloua curtipendula* cover was significantly higher in 2006 in the fall-planted area than in any other season x year combination (interaction effect $F_{2, 16} = 3.93$, $P = 0.04$), while *B. gracilis* cover was 360% greater in the spring-planted areas than fall-planted areas ($P = 0.04$, Table 2). No other year ($F_{2, 16} \leq 2.62$, $P \geq 0.10$) or season x year effects were significant ($F_{2, 16} \leq 2.59$, $P \geq 0.11$).

Planting and Revegetation Success

Overall, *B. gracilis* appeared to be the most successful of the five grass species planted, while *B. dactyloides* was the least successful. *Buchloë dactyloides* had consistently low cover (< 0.5%) throughout the three years, both in the disturbed areas and in the nearby reference vegetation (Figure 2). Two species, *B. gracilis* and *N. viridula*, had higher cover in the areas where they were planted than in the reference vegetation in all three years, and *P. smithii* followed this pattern in 2005 and 2006. *Bouteloua curtipendula* and *B. gracilis* cover increased significantly over time in the disturbed, but not reference, vegetation, and *N. viridula* cover followed this pattern, but not significantly (Table 3, Figure 2). Despite the increase in these species, their percentage of the total plant cover in the disturbed vegetation remained similar over time, even though this percentage decreased in the reference vegetation (Table 3, Figure 3).

Differences in native species richness between reference and disturbed vegetation varied marginally ($P = 0.066$) among years, with 2004 disturbed vegetation and 2005 reference vegetation having slightly higher native species richness than 2006 reference vegetation (Table 3, Figure 3). Total plant cover was consistently, though only marginally significantly ($P = 0.069$), higher in the reference vegetation than in the disturbed area, though the difference was not great (~5%). Exotic species cover did not differ between reference and disturbed vegetation, but it was significantly lower in 2004 than in the other two years, as was total plant cover. Soil and rock cover decreased over time in the disturbed area but was constant in the reference vegetation. Litter cover, on the other hand, decreased from 2004 to 2005 and 2006 in the reference vegetation, but was similar in 2004 and 2006 in the disturbed areas (Table 3, Figure 4).

Plant community composition was significantly different between the disturbed and reference vegetation in all three years of the study (MRBP $P = 0.001$ for each of the three years), and the Jaccard similarity index did not change through time ($F_{2,27} = 1.72$, $P = 0.20$; average value over three years = 0.43). The difference in composition is evident in the relatively distinct separation of the transect types on the first PCA axis throughout the study (Figure 5). Two of the five planted species were associated with the disturbed vegetation in 2004, but this association decreased through time, so that no planted species were strongly correlated with the first PCA axis in 2006. *Koeleria macrantha* was the only species consistently associated with the reference vegetation, though *Carex* species were associated with the reference vegetation in two of the three years of the study. The relatively similar location of transect pairs on the second PCA axis in each graph suggest that this axis separated transects by species specific to their location along the water line. In 2006, for example, transect pairs 9 and 10, which were close to the visitor center complex and protected from grazing, fell at the high end of this axis. It should be noted that these two axes only accounted for about one third of the total variance among transects (average of 17% for the first axis over the three years).

Visual inspection of the graph of the first two principle components from the 2004-2006 PCA (Figure 6) suggests that vegetation in six of the ten disturbed transects was changing towards that of the reference vegetation, but for half of these, composition of the reference vegetation was changing in a similar direction as the vegetation in the disturbed area. Over all, the rate of change between reference and disturbed transects did not differ significantly ($t = 0.90$, df = 9, $P = 0.39$).

<u>Individual Species Differences</u>

Quantitative information on the individual species that distinguish the disturbed and reference areas may suggest those species that are particularly good or bad at colonizing and/or surviving in the disturbed area. Seventeen species were significant indicators of disturbed vegetation ($P < 0.10$; Table 4). Four of these were planted during the revegetation effort, and three (*Bromus japonicus*, *Medicago lupulina*, and *Melilotus officinalis*) are exotic. One exotic species (*Poa pratensis*) was a significant indicator of reference vegetation. The fourteen other species that were significant indicators of reference vegetation included six forbs, six grasses, and two sedges (Table 4).

Part 2: Comparing Seed Mixes in Experimental Plots

Viability of locally collected seed varied considerably, from 25% for *Brickellia eupatorioides* to 99% for *Onosmodium molle* (Table 5). Viability data for three species in the grass-only seed mix allow a comparison between locally collected and commercially grown species. Locally collected seeds for *B. curtipendula* and *S. scoparium* had lower viability than their commercially grown counterparts, whereas locally collected *N. viridula* had essentially the same viability as the commercial seed.

Plot-Level Measures of Success

Planting season and its interactions with seed mix and/or sampling year did not significantly ($P > 0.10$) affect any of the aggregate plant community measures evaluated. Thus, seed mix and sampling year are the only effects evaluated for plot-level measures of success.

The proportion of total plant cover comprised by species planted anywhere in the experiment was substantial in all seed mixes (Figure 7a) and differed only marginally among the eight seed mixes and the control (Table 6). This proportion was high even in the unseeded control, where species planted elsewhere in the experiment comprised 47% of the plant cover, suggesting a relatively high level of residual vegetation resprouting from remnants left in the soil after site preparation. Based on 2005 non-seedling cover, *R. arkansana* was the most abundant of the residual species, followed by *Psoralidium tenuiflorum*, *P. smithii*, *Verbena bracteata*, and *Symphoricarpos occidentalis*.

This residual was likely at least partly responsible for the fact that total cover of neither native nor exotic species differed significantly among seed mixes, although cover of both of these groups did increase significantly from 2005 to 2006 (Table 6). The increase in exotic cover (17% in 2005 to 26% in 2006, least squares means; SE = 1.6) was consistently (across treatments) greater than the increase in native cover (32% to 37%; SE = 2.4).

Native species richness remained constant over the two years of sampling, but it did differ significantly among seed mixes (Table 6). Native richness was lowest in the two grass-only mixes and the control. However, only three seed mixes had significantly greater native species richness than the controls. These were the two mixes in the low C-value treatment and one of the mixes in the mixed C-value treatment (Figure 7b).

The adjusted seedling number is a measure of the field germination success of the planted species. This value varied differently among seed mixes depending on the sampling year (Table 6, Figure 8a). In 2005, adjusted seedling number was similar among all mixes except mix H2, which had the lowest germination success. This mix had only about half the adjusted seedling number of the other mixes, which was approximately 8%. Planted species seedling numbers declined from 2005 to 2006 for four mixes, remained the same for three mixes, and increased for one mix (Figure 8a). In 2006, six of the eight mixes had adjusted seedling numbers similar to those of the lowest-germinating mix in 2005, but mixes L1 and M1 sustained their high adjusted seedling number. Over the two years of data collection, mixes L1 and M1 had the greatest success, whereas mix H2 the least success, when success is measured as germination of planted seeds (Figure 8b).

Another measure of success is the size, measured as foliar cover, of the seedlings of the planted species. This value was generally low (1.6-8.0%), but there was significant variation among mixes, and this varied between years (Table 6). The greatest difference in seedling cover between years occurred in the low C-value mixes (L1 and L2). These mixes had significantly greater seedling cover than all other mixes in 2005, but seedling cover in these mixes decreased significantly in 2006 so that they did not differ from the other mixes (Figure 9a).

The cover of species planted in a plot as a proportion of the total plot cover is another measure of planting success; however, it is a rough measure because it includes both seedling cover and cover from the residual vegetation of the planted species. In the second year after planting, it also includes the cover of the 2005 seedlings that survived to 2006. Thus, it would be expected that this proportion would increase from 2005 to 2006. When all mixes were evaluated collectively, this expectation was met (Table 6), but not all mixes followed this trend (Figure 9b). This proportional cover significantly increased from 2005 to 2006 in four of the eight mixes. The greatest increase was for the commercially grown grass-only mix (mix PMC), which had the second lowest value in 2005 but the second highest value of all the mixes in 2006, increasing from 10 to 30% of total cover. This proportional cover also increased in the locally collected grass-only mix (mix PML) and the two mixed C-value mixes. As with seedling numbers, mix

H2 consistently had the lowest, and mix L1 the highest, proportional planted species cover. Both of these mixes' planted species cover decreased from 2005 to 2006 (Figure 9b)

In 2006, six of the eight seed mixes had significantly more seedlings of their planted species than did the controls, and there were significant differences among mixes in this comparison (Table 6, Figure 10a). The two seed mixes with the greatest number of their species' seedlings in the control plots (L1 and M1; Figure 10b) also had the greatest difference between planted plots and controls (Figure 10a). The three seed mixes with the smallest difference between planted plots and controls (L2, H2, and PMC) also had the lowest number of planted species seedlings in 2006 alone or in the two years combined (Figure 10a vs. Figure 8). Together, these results suggest that, although the background seed levels of the planted species were greater than ideal, differences in the seedling numbers and cover among planted mixes were real.

Species-Level Measures of Success

Adjusted seedling number and seedling cover were not significantly different ($P > 0.10$) between locally collected and commercially grown seeds for three of the four species in the grass-only mixes. Adjusted seedling number of *N. viridula* in the commercial mix was twice that in the locally collected mix ($F_{1,8} = 6.2$, $P = 0.038$), and seedling cover of this species in the commercial mix was approximately half again as high as in the locally collected mix ($F_{1,8} = 14.7$, $P = 0.005$). Because no other species differed significantly between mixes and for simplicity, locally collected and commercially grown seeds were combined in the remainder of the species-level analyses.

Adjusted seedling number differed significantly among species when combined over all mixes. These differences varied between the two planting seasons, and germination success of species differed between seasons for some species (Table 7). In the fall-planted plots, the 2005 adjusted seedling number was >10% for five forbs (*Echinacea angustifolia*, *Helianthus annuus*, *V. bracteata*, *Asclepias speciosa*, and *G. squarrosa*) and one grass (*N. viridula*). Four of these species (*V. bracteata*, *E. angustifolia*, *G. squarrosa*, and *H. annuus*) also had >10% adjusted seedling number in the spring-planted plots, as did three grama grasses (*B. gracilis*, *B. curtipendula*, and *B. hirsuta*) and two forbs (*Heterotheca villosa* and *Dyssodia papposa*). Only three species had high seedling numbers in 2006 – *D. papposa* in both fall- and spring-planted plots, *H. annuus* in fall-plantings only, and *B. hirsuta* in spring plantings only (Table 8).

There were more differences in germination between fall and spring plantings in 2005 than in 2006. In 2005, *Penstemon grandiflorus, E. angustifolia, and N. viridula* had greater germination in fall-planted plots than in spring-planted plots, whereas *B. gracilis*, *B. eupatorioides*, *B. curtipendula*, *Liatris punctata*, *H. villosa*, *V. bracteata*, and *Gutierrezia sarothrae* had greater germination in spring than fall plantings. In 2006, seedling numbers for four species (*B. eupatorioides*, *B. hirsuta*, *Aristida purpurea*, *and H. villosa)* were greater for spring than fall plantings (Table 8).

The cover of planted species' seedlings also varied among species and between the two planting seasons (Table 7). Seedling cover in 2005 was greatest (>0.5% averaged over all plots in which the species were planted) for *H. annuus*, *V. bracteata*, *Ratibida columnifera*, *D. papposa*, *N. viridula*, *E. angustifolia*, *and G. squarrosa* (decreasing order of seedling cover) in fall-planted plots. Four of these species (*H. annuus*, *V. bracteata*, *R. columnifera*, and *D. papposa*) were also the most successful in terms of cover in the spring-planted plots, as were *P. tenuiflorum*, *B. gracilis*, and *B. curtipendula*. In 2006, only five species had >0.5% seedling cover: *P. tenuiflorum* and *Sporobolus cryptandrus* in fall-planted plots, and *B. curtipendula*, *S. cryptandrus*, *D. papposa*, and *B. hirsuta* in spring-planted plots. *Helianthus annuus* and *P. tenuiflorum* seedlings had significantly greater cover in fall-planted plots, and *V. bracteata*, *B. curtipendula*, *B. hirsuta*, *and A. purpurea* had greater cover in spring-planted plots (Table 8).

Both adjusted seedling number and seedling cover varied widely among species with the same C-value, and there was little consistent pattern among C-values (Figure 11). The only clear distinction was that the three species with a C-value of 0 (*H. annuus*, *D. papposa*, and *V. bracteata*) had high seedling cover in 2005, and the two species with the highest C-value (*Ipomoea leptophylla* and *A. canescens*) had very low germination rates and seedling cover in both years.

Laboratory-measured viability of the seeds varied considerably (Table 5), but this seemed to have no relationship to the results in the field. Excluding the species planted in the grass-only mixes, twenty species planted in the experiment had data for field germination (adjusted seedling number) and laboratory viability. The linear correlation between these two variables was not significant ($R^2 = 0.02$, $P = 0.56$).

Seedling data collected in 2006 in the control plots suggests either that there was a substantial soil seed bank of many of the planted species in the planted area, or that the seeds that were experimentally planted did not stay in the plots to which they were added. There was a significant difference in seedling numbers between planted plots and their respective controls for only six species (*B. curtipendula*, *B. gracilis*, *B. hirsuta, D. papposa, S. scoparium, and Solidago nemoralis*; Tables 7 and 8). Lack of similar data from 2005, when the greatest seedling numbers occurred (Table 6) and the difference in seedling numbers between planted plots and their controls may have been more substantial, makes it difficult to conclusively say how many of the differences among species shown above are real. The results are thus presented with this acknowledgement of confounding factors, rather than throw out the results entirely.

A different measure of success of individual species that is not confounded by residual vegetation is the mortality of the seedlings that did emerge. Mortality during the 2005 growing season and over the 2005-06 winter differed significantly among species but not between planting seasons (Table 7). Most species had relatively low mortality during the first growing season after planting; 28 of 33 species for which this measure is applicable had, on average, more than 80% of the seedlings present in the first data collection period (May-July) still present in the second data collection period (August-September). Of the five remaining species, four (*Achillea millefolium*, *Plantago patagonica*, *L. punctata*, *and I. leptophylla*), had very low (<1%) adjusted seedling number, and therefore very few individual seedlings. Winter mortality was >50% for 19 of the 31 species that had more than one seedling remaining at the end of the first growing season. This included the three grama grasses (*B. curtipendula*, *B. gracilis*, and *B. hirsuta*), which were consistently successful in germination. Mortality during the second growing season, which includes death of 2005 and 2006 seedlings, was approximately four times greater than in the first growing season (overall average 44% vs. 11%). This mortality varied significantly among species, and, for five species, between fall-planted and spring-planted plots. *Amorpha canescens*, *E. angustifolia* and *P. grandiflorus* had greater 2006 mortality in spring-planted plots, whereas *A. ludoviciana* and *Erysimum asperum* had greater 2006 mortality in fall-planted plots (Table 8). There was no consistent pattern of mortality among species by C-value (Figure 12).

DISCUSSION:

Part 1: Assessing the Water Line Revegetation Project

By some measures, revegetation of the water pipeline project has succeeded. Five years after planting, four of the five planted species were well established and three of these species were still increasing in their cover. Native species richness and exotic cover in the disturbed area were similar to nearby undisturbed vegetation, and total plant cover was only slightly lower. In addition, the ground cover (bare soil & rock *versus* litter) seems to be converging between the disturbed and reference areas.

By other measures, the revegetation is not yet complete. An implicit assumption in many revegetation projects is that the composition of the planted community will gradually converge with that of the target, or reference vegetation, through the process of "spontaneous succession" (Prach et al. 2001b). This is particularly true in situations like the water line project studied here – a relatively small disturbance surrounded by a large area of intact vegetation (Prach et al. 2001a) . This convergence would be expected to occur as the planted species (which are basic components of the surrounding vegetation) become established and other species colonize the area through seeds and vegetative spread. Thus, most of the convergence is expected to occur from the disturbed area becoming more similar to the relatively stable surrounding vegetation.

This expected convergence has been weak in the three years of this study. Plant community composition as a whole remained significantly different. Also, although the direction of the disturbed area's composition change was more consistent than the surrounding community's, the rate of change was not any faster.

There are many possible reasons for this weak convergence. First, some species are better at spreading into new areas than others. Seed dispersal methods (i.e., by animals, wind, or gravity) determine the distance that a seed will travel from the parent plant, and therefore the likelihood that it will colonize an area. For vegetative spread, rhizomatous or stoloniferous species can spread greater distances than bunch grasses or tap-rooted forbs. *Ambrosia psilostachya* performed comparatively well in the disturbed area in this study perhaps because of its ability to reach the area quickly, both through seed and rhizomes. Barbs or hooks on the seeds of the exotic annual brome, *B. japonicus*, aid the seeds in attaching to the fur of animals, which eases their spread to new areas. The sticky seeds of curly-cup gumweed (*G. squarrosa*) act similarly. The copious amount of seeds produced by individual yellow sweetclover (*M. officinalis*) plants increase its chances of reaching an appropriate area for germination (Turkington et al. 1978). Most of the species that were comparatively more abundant in the undisturbed area do not have these kind of adaptations, but some do. For example, *Artemisia ludoviciana* and *P. pratensis* are rhizomatous, and *S. scoparium* and *A. gerardii* are wind-dispersed. Thus, other factors contribute to the success of some species over others in disturbed areas.

Differing environmental conditions between the disturbed and undisturbed areas are the other most likely reason for lack of convergence so far. Organic material in the topsoil may have been lost or buried when the soil was dug up and replaced, thereby reducing nutrient levels and potentially affecting soil water holding capacity. (No soil samples were taken to confirm this speculation, however.) Lower live plant cover reduces the amount of shade available, thereby potentially making young plants more susceptible to desiccation, and higher litter cover in the mixed grass prairie often increases soil moisture (e.g., Willms et al. 2002). Finally, climate patterns since the disturbed areas were planted may not have met the germination and establishment requirements of some species.

The data that can be used to compare the effectiveness of spring to fall planting seasons in this part of the study are not ideal because the areas planted in each of the seasons were not chosen randomly. The fall planting was done near the visitor center, in an area from which bison are excluded, whereas the spring planting was done over a much larger area over which bison are free to roam. Therefore, the environmental conditions of the plantings are not independent of their planting season. Keeping this in mind, there was little effect of planting season on the success of four out of the five species planted in this project. *Bouteloua gracilis* is the exception, in that its density and cover were greater in spring-planted transects. This effect for *B. gracilis* is consistent with the results of the experimental plantings in the second part of the study.

Part 2: Comparing Seed Mixes in Experimental Plots

The results of this portion of the study must be interpreted in the correct context. The experiment was originally designed for a situation in which the soil would have been highly disturbed due to substantial contouring of the ground surface, leaving little remnant vegetation – a situation similar to what is expected after substantial construction projects. Due to circumstances beyond the park's control, the experiment had to be implemented in an area that had significant vegetation already. The park does not allow herbicide use in this area, so seed bed preparation for the plantings was limited to scraping the existing vegetation and soil with a grader. This preparation provided adequate opportunity for seeds to have good contact with the soil, but many existing plants were able to resprout from roots. It is clear from the results that five of the planted species were already relatively abundant in the area and were able to recover from the seedbed preparation disturbance. In addition, either a substantial seed bank of many of the planted species already existed in the soil, or dry and windy conditions after the fall planting resulted in the movement of planted seeds among plots, including into the controls. The latter seems more likely for most of the species planted, given the degraded state of the vegetation at the outset of the experiment and the generally low levels of conservative native grassland species in the seed banks of degraded grasslands (e.g., Romo and Bai 2004, Henderson and Naeth 2005, Symstad 2007). Although these problems complicate the interpretation of the results, useful information for future plantings can still be derived from the project.

The occurrence of species other than those planted, particularly short-lived weedy species, is not unusual in restoration plantings, as described in the Introduction. This experiment investigated the possibility of precluding weedy exotic species by planting native species that are generally found in disturbed areas, and therefore would be expected to fare well in the disturbed conditions of a restoration planting. In contrast to this expectation, there were no differences in total native or exotic plant cover among the seed mixes comprised of disturbance-adapted (low C-value) *versus* disturbance-sensitive (high C-value) species. Thus, at least in this situation, low C-value native species did not provide adequate competition for undesirable exotic species. Some seed mixes, especially those comprised of more disturbance-adapted species (mixes L1 and L2), did increase native species *richness* over that of control vegetation, however.

Overall, differences in emergence and early growth of the planted species among seed mixes were generally more dependent on the individual species that comprised them than on their composition in terms of C-value. Mixes with the same C-value composition differed significantly in many measures of success. The only exception to this pattern is that both seed mixes in the low C-value treatment had higher seedling cover than other mixes in the first growing season after planting. Three species – *H. annuus* and *D. papposa* in seed mix L1, and *V. bracteata* in seed mix L2 – were largely responsible for this high cover. Both *H. annuus* and

D. papposa are annuals, and *V. bracteata* can also be an annual. Herbivory of *H. annuus*' seed heads at the end of the 2005 growing season reduced the opportunity for this species to re-seed itself and probably contributed to its decline in seedling numbers and cover from 2005 to 2006. Lower natural precipitation and supplemental watering also probably caused lower cover of all of these species in 2006 (Figure 11).

One seed mix, H2, performed particularly poorly, both in terms of seed germination and cover of planted species. This was likely due to the fact that seedlings of one of the three species seeded at the highest rate in this mix, *Solidago missouriensis*, were rarely encountered. It should be noted that difficulties in distinguishing this species from *S. nemoralis* and other forbs may have artificially reduced the seedling counts in this seed mix. However, this mix's low success is also attributable to the fact that, of the remaining species in this mix, only one (*B. gracilis*) had a high germination rate.

There was surprisingly little difference in success between the commercially grown and locally collected grass-only mixes or their individual species, despite generally lower viability rates of the locally collected seed. Commercial and local seed differed only for *N. viridula*, and this difference is unlikely due to seed viability, since seeds from both sources had equally high laboratory-measured viability (93-95%).

Although season of planting had no significant effect on any of the mixes as a whole, it did seem to affect the success of individual species. More species were successful in spring plantings than fall plantings than vice versa, but overall, most species did equally well in either planting season. However, for use in future plantings, it is worth noting those species that did respond differently. The most extreme differences were for two forbs, *B. eupatorioides* and *H. villosa*, which had approximately 15 and 40 times the germination rate in spring plantings than in fall plantings, respectively. On the other hand, *E. angustifolia* germination in fall plantings was more than twice that in spring plantings, and, based on 2006 mortality rates, fall-planted seedlings of this species appear to have been more robust than those in spring plantings. The commonly planted and relatively successful, warm-season grama grasses (*Bouteloua* spp.) all did better in spring than in fall planting, but *N. viridula*, a cool-season species, showed a tendency towards greater germination success when planted in the fall. These planting-season effects on grasses are consistent with general recommendations that cool-season species be planted when soil temperatures are cool (fall or early spring) and warm-season species be planted when soil temperatures are warm (late spring) (Diboll 1997, Boltz 2006).

The high mortality rates for most species in 2006 compared to 2005 suggest that water was a critical factor in the survival of the seedlings. This is to be expected given the hot, dry, and windy conditions that often occur in this region during the growing season, but it suggests that watering in plantings such as these must be maintained longer than a single season for the best probability of planting success. In the drier year, the species with the lowest mortality rates tended to be grasses (Figure 12).

Improving the Success of Native Grassland Plantings in the Northern Great Plains

Understanding the factors that determine species' tolerance to and growth in a variety of conditions is key to predicting their success in the harsh conditions of a semi-arid grassland planting, as well as for knowing at what point in a restoration that species should be introduced. General patterns for predicting which plant species respond positively to disturbance and which can tolerate various environmental conditions have been deduced from the study of individual plant traits (Grime et al. 1988, Lavorel et al. 1999, Lavorel & Garnier 2002). Applicability of this type of research to flora other than those from which the patterns were deduced is difficult, however, because of the lack of available data (quantitative trait information) on individual species. Consequently, this study attempted to use the coefficient of conservatism (C-value) as an index of disturbance-tolerance traits.

Debate surrounding the utility of this coefficient and derived indices of floristic quality (e.g., Bowles and Jones 2006; Taft et al. 2006) makes it imperative that it be tested in a variety of ways (Lopez and Fennessy 2002). The 40 species used in this experiment comprise approximately 7% of the species that occur in the park. Although this is a relatively small fraction, it is a large sample of the species that could be used in grassland plantings in this region. Based on this sample, there is little evidence that C-value is a useful predictor of species' success early after planting. Species with the same C-value exhibited a wide range of success by any of the measures used in this study – germination, cover, or mortality. Thus, this study suggests that the coefficient of conservatism ranking system may be more useful for evaluating the state of degradation or progress in restoration of natural areas than for predicting success in restorations (e.g., Bourdaghs et al. 2006, Taft et al. 2006).

Abundance of species in the disturbed vegetation of the water line project was a somewhat better predictor of success in the experimental plots, but it was not consistent. *Sporobolus cryptandrus, Elymus elymoides* and *G. squarrosa* naturally recruited into the disturbed vegetation so that they were indicator species of this vegetation. *Sporobolus cryptandrus* and *G. squarrosa* were also relatively successful in the experimental plots, where their seedling cover was 6th and 8th greatest of the 40 species planted and tracked. In contrast, only 8 of the 40 planted species had lower seedling cover than *E. elymoides*. On the other hand, of the seven species planted and tracked in the experimental plots that were indicative of native prairie reference vegetation, their rank in seedling cover ranged from 11th (*E. angustifolium*) to 31st (*Hesperostipa comata*), with an even split of those seven species between above and below the median seedling cover.

What, then, can be done to predict and improve the success of individual species and entire seed mixes in restoration plantings? A key step is to routinely, consistently, and quantitatively monitor these restorations over a long time period. The results of this study may be substantially different if the vegetation in both the waterline revegetation project and the experimental plots were evaluated five years from now. In addition, the results of this monitoring need to be widely available so that mistakes are not repeated and successes can be built upon. For example, the poor performance of *B. dactyloides* in the water line revegetation project suggests that planting it in situations like this is not the best use of funds.

Another step is to methodically attack the problems faced in grassland restorations. Some general rules of thumb for native grassland plantings illustrate these problems. One “rule” is that a native grassland restoration will have the appearance of a disturbed site for the first 2-3 years after planting, in that weedy species will dominate and planted species will be relatively small. The experimental plots of this study did not follow this rule completely because of the high amount of native residual vegetation, but the small size of the seedlings of the planted species was consistent with the rule. Another rule of thumb is “What you plant is what you get.” In other words, desirable native species from the surrounding landscape are slow to colonize the planting on their own (Kindscher and Tieszen 1998, Sluis 2002). The significantly different composition between the water line and the nearby native vegetation follows this rule of thumb. The low success of many of the planted species in the experimental plots suggests that the rule might more accurately be stated as “What you get is some portion of what you plant.” For the semi-arid northern Great Plains, an additional rule should probably be "Plan on dry conditions." Thus, research needs to focus on rapid establishment of native species, methods to increase the species richness and diversity of plantings, either from the outset or over a longer time period, and means to accomplish these economically even in sub-optimal climatic conditions.

SUMMARY:

This study quantitatively evaluated the success of a native grass revegetation project five years after its planting and experimentally compared a variety of seed mixes for native grassland restoration at Wind Cave National Park in southwestern South Dakota.

Five years after planting in the water line revegetation project:

- Four out of the five planted species were successfully established, *Buchloë dactyloides* (buffalograss) being the exception.
- Exotic species cover and native species richness in the planted area were similar to, and total plant cover only slightly lower than, that in adjacent native vegetation.
- The amount of bare ground decreased since monitoring began, but it was still significantly greater than in native prairie, making the planted area still visually different.
- Species composition of the plant community in the planted area was significantly different from the native prairie, with some exotic species such as *Melilotus officinalis* (yellow sweetclover) being more abundant in the planting than in the native prairie.

In the two years of monitoring of the experimental plots:

- Planted species remained a minor portion of the total plant cover in all of the experimental treatments.
- The coefficient of conservatism was not a good predictor of species' establishment and growth success in the planting.
- Three species fared better when fall-planted, and seven species fared better when spring-planted. However, most species were insensitive to whether they were planted

in spring or fall, yielding no overall difference in spring vs. fall planting success at the seed mix level.

- Early successional annuals, particularly *Helianthus annuus* (common sunflower), *Verbena bracteata* (bigbract vervain), and *Dyssodia papposa* (fetid marigold), produced relatively high cover in the first growing season after planting, but this cover was not sustained in the second growing season.
- Commercially grown and locally collected grass seeds performed similarly.
- High temperatures and low precipitation in the second growing season after planting caused high mortality for many seedlings, although grasses seemed to fare better than forbs.

This study provides a quantitative comparison of the success of a wide variety of species native to Wind Cave National Park grasslands in a grassland restoration setting. Although the circumstances of the restoration were somewhat unusual compared to most restoration plantings, the information on individual species will be useful for future plantings regarding which are most likely to germinate and survive, and whether they perform better when planted in fall or spring. No matter which species are used in future plantings, the results of the study show that resources dedicated to a reliable and effective watering regime are warranted to ensure the establishment of as many planted species as possible.

Further monitoring of the plots used in this study, particularly the experimental plots, would improve the understanding of the long-term effectiveness of the plantings, since the length of this study is short compared to the normal time required for grassland plantings to be adequately evaluated. Further research needs to focus on rapid, economical establishment of a broad variety of native species, even in sub-optimal climatic conditions.

ACKNOWLEDGEMENTS

Helen McGranahan and Leigh Stansfield did the lion's share of the field work and data entry for this project. I thank them for their efforts and careful attention to detail. Molly Benson also assisted with field work and data collection. Marie Curtin and Dan Foster were instrumental in determining the need for this project and for helping with logistics of working in the park. I also thank Deb Buhl and Wes Newton for guidance in statistical analyses and Cyni Brown, Deb Buhl, Jack Butler, and John Taft for their helpful comments on an earlier version of this report.

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Table 1. Summary of treatments and seed mixes for experimental planting at Wind Cave National Park.

Treatment	Mix	C range	C average	Grass Species	Forb Species	Shrub Species	Seed Origin
Low C-value	L1	0-5	3.14	3	9	2	locally collected
	L2	0-5	3.21	2	11	1	locally collected
High C-value	H1	5-9	6.43	5	7	2	locally collected
	H2	5-9	6.36	5	8	1	locally collected
Mixed C-value	M1	0-9	4.93	5	7	2	locally collected
	M2	1-7	4.86	5	8	1	locally collected
Previous mix	PML	4-7	5.40	5	0	0	locally collected
	PMC	4-7	5.40	5	0	0	commercially grown
Control	C	--	--	0	0	0	--

Table 2. Least squares mean (se) number of individuals and percent cover per 0.5 m^2 for five species planted in water line disturbance, separated by planting time. Values are averaged over 2004-2006. ”F” and “P” columns indicate significance of planting time effect in ANOVA testing for effects of planting time, year of data collection, and their interaction. Only for *Bouteloua curtipendula* cover was year- or year x planting-time effect significant (see text).

	Number of Individuals				**Cover (%)**			
Species	**Fall 2000**	**Spring 2001**	***F****	***P***	**Fall 2000**	**Spring 2001**	***F****	***P***
B. curtipendula	0.8 (0.5)	1.8 (0.2)	3.2	0.11	2.5 (0.7)	1.9 (0.4)	0.6	0.45
B. gracilis	0.9 (0.9)	3.7 (0.4)	8.0	0.02	1.7 (1.7)	6.1 (0.8)	5.8	0.04
B. dactyloides	0.1 (0.1)	0.2 (0.1)	0.5	0.49	0.1 (0.2)	0.2 (0.1)	0.4	0.56
N. viridula	0.6 (0.7)	1.5 (0.3)	1.4	0.27	2.6 (1.5)	2.3 (0.7)	0.03	0.86
P. smithii	4.0 (3.7)	6.0 (1.9)	0.2	0.65	2.0 (1.3)	2.1 (0.7)	0.00	0.96

*df = 1, 8.

Table 3. Effects of vegetation type (reference vs. disturbed), year of data collection (2004, 2005, 2006), and their interaction on the five planted species, their total cover as a percentage of total plant cover, and other vegetation characteristics along the water line revegetation project.

	Type df = 1, 9		Year df = 2, 18		Type x Year df = 2, 18	
Variable	*F*	*P*	*F*	*P*	*F*	*P*
B. curtipendula cover	8.8	0.016	1.2	0.33	9.5	0.002
B. gracilis cover	21.0	0.001	3.5	0.053	6.7	0.007
B. dactyloides cover	0.1	0.79	1.1	0.36	0.6	0.56
N. viridula cover	10.3	0.011	1.5	0.24	1.4	0.27
P. smithii cover	10.2	0.011	3.7	0.046	3.4	0.054
Planted species % of total cover*	51.2	<0.001	7.2	0.005	9.3	0.002
Total plant cover	4.3	0.069	82.0	<0.001	2.3	0.13
Exotic species cover*	0.3	0.61	10.5	<0.001	2.4	0.12
Bare soil and rock cover*	69.4	<0.001	16.2	<0.001	30.4	<0.001
Litter cover	32.6	<0.001	23.2	<0.001	38.1	<0.001
Native species richness	0.5	0.49	3.5	0.051	3.2	0.066

* Variables were arcsin-square root (planted species percentage) or log (exotic species and bare soil-rock cover) transformed for analyses.

Table 4. Species with a significant or marginally significant (P < 0.10) indicator value for either reference or disturbed vegetation. Full species names are in Appendix 1.

Species	Group	Indicator Value	*P*
Carex species	reference	80.7	0.001
C. filifolia	reference	66.6	0.001
S. scoparium	reference	64.7	0.013
B. hirsuta	reference	64.2	0.001
A. gerardii	reference	60.1	0.021
P. pratensis†	reference	59.8	0.096
H. comata	reference	59.3	0.009
A. ludoviciana	reference	53.9	0.003
K. macrantha	reference	52.8	0.001
G. coccinea	reference	50.7	0.055
P. hoodii	reference	45.9	0.001
L. punctata	reference	43.4	0.013
E. angustifolia	reference	40.2	0.070
D. purpurea	reference	39.8	0.012
M. cuspidata	reference	31.9	0.068
*N. viridula**	disturbed	85.9	0.001
*B. gracilis**	disturbed	79.6	0.001
S. cryptandrus	disturbed	77.4	0.001
*P. smithii**	disturbed	69.8	0.001
A. psilostachya	disturbed	65.1	0.002
V. stricta	disturbed	60.5	0.001
D. oligosanthes	disturbed	56.3	0.001
*B. curtipendula**	disturbed	54.7	0.068
B. japonicus†	disturbed	51.5	0.072
G. squarrosa	disturbed	47.1	0.001
S. ericoides	disturbed	46.2	0.094
L. incisum	disturbed	43.5	0.036
S. missouriensis	disturbed	41.7	0.001
M. officinalis†	disturbed	40.0	0.001
E. elymoides	disturbed	29.4	0.038
M. lupulina†	disturbed	27.1	0.013
E. trachycaulus	disturbed	25.4	0.038

*planted species; †exotic species

Table 5. Viability of seeds used in seed-mix comparison experiment. Numbers in parentheses are seed viability for commercially grown seeds.

Species	% Viable
Amorpha canescens	80
Andropogon gerardii	59
Aristida purpurea	89
Artemisia frigida	72
Asclepias speciosa	82
Bouteloua curtipendula	41 (81)
Bouteloua hirsuta	42
Brickellia eupatorioides	25
Cirsium undulatum	67
Elymus elymoides	91
Helianthus petiolaris	62
Hesperostipa comata	71
Ipomoea leptophylla	67
Liatris punctata	58
Nassella viridula	95 (93)
Onosmodium molle	99
Penstemon grandiflorus	97
Psoralidium tenuiflorum	95
Ratibida columnifera	58
Rosa arkansana	64
Schizachyrium scoparium	69 (91)
Sporobolus cryptandrus	84
Symphoricarpos occidentalis	47
Symphyotrichum ericoides	69
Verbena bracteata	74

Table 6. Effects of seed mix, sampling year, and their interaction on aggregate plant community measures in experimental plantings at Wind Cave National Park.

	-------Mix Effect-------			-Sampling Year Effect-			--Mix x Year Effect--		
Measure	**df**	***F***	***P***	**df**	***F***	***P***	**df**	***F***	***P***
Experiment-planted species' cover as proportion of all species' cover	8, 64	1.8	0.093	1, 72	6.34	0.014	8, 72	0.35	0.94
Native cover	8, 64	1.6	0.13	1, 72	29.1	<0.001	8, 72	1.3	0.24
Exotic cover	8, 64	1.7	0.12	1, 72	118.6	<0.001	8, 72	0.78	0.62
Native species richness	8, 64	2.1	0.054	1, 72	0.00	1.00	8, 72	0.99	0.45
Plot-planted species' adjusted seedling number	7, 56	3.3	0.0048	1, 64	22.1	<0.001	7, 64	5.8	<0.001
Plot-planted species' seedling cover	7, 56	8.9	<0.001	1, 64	26.7	<0.001	7, 64	6.3	<0.001
Plot-planted species total cover as proportion of all species' cover	7, 56	8.8	<0.001	1, 64	134.8	<0.001	7, 64	15.4	<0.001
Control seedling number*	7, 56	11.1	< 0.001	NA	NA	NA	NA	NA	NA
Mix - Control seedling number*	7, 56	2.1	0.057	NA	NA	NA	NA	NA	NA

*data collected only in 2006, therefore sampling year effect not applicable (NA)

Table 7. Effects of species, season planted, and their interaction on various measures of success of species planted in experimental plots at Wind Cave National Park.

	--------Species--------			---Planting Season----			--Species x Season---		
Measure	df	*F*	*P*	df	*F*	*P*	df	*F*	*P*
Adjusted seedling number, 2005	39, 307	19.0	<0.001	1, 8	0.91	0.37	39, 307	3.7	<0.001
Adjusted seedling number, 2006	39, 307	7.9	<0.001	1, 8	0.6	0.45	39, 307	1.4	0.049
Seedling cover, 2005	39, 312	9.8	<0.001	1, 8	0.2	0.65	39, 312	2.5	<0.001
Seedling cover, 2006	39, 312	13.3	<0.001	1, 8	0.5	0.49	39, 312	1.6	0.020
Mix - control seedling number, 2006	39, 312	6.5	<0.001	1, 8	0.5	0.51	39, 312	0.3	1.00
2005 growing season mortality	32, 198	6.2	<0.001	1, 8	0.0	0.99	32, 198	1.3	0.12
2005-06 winter mortality	30, 187	5.0	<0.001	1, 8	0.2	0.67	30, 187	0.9	0.57
2006 growing season mortality	33, 207	13.2	<0.001	1, 8	1.6	0.24	33, 207	1.6	0.033

Table 8. Least-squares means for measures of success for individual species in experimentally planted plots at Wind Cave National Park. Different means are shown for fall-planted (F) and spring-planted (S) plots if there was a significant species x season interaction for that measure (Table 7). Cells with "." indicate that mortality rate for at least one planting season could not be calculated. "nt" means the species was not tracked for mortality, since it is an annual. Where necessary, values are back-transformed.

	2005 Adjusted Seedling # (%)*		**2006 Adjusted Seedling # (%)***		**2005 Seedling Cover (%)***		**2006 Seedling Cover (%)***		**2006 Mix – Control Seedling Number** †	**2005 Growing Season Mortality (%)**	**2005-06 Winter Mortality (%)**	**2006 Growing Season Mortality (%)***	
Species	**F**	**S**	**F**	**S**	**F**	**S**	**F**	**S**				**F**	**S**
Achillea millefolium	0.1	2.1	0.0	2.2	0.10	0.15	0.00	0.10	0.7	42.9	.	.	.
Amorpha canescens	0.3	0.0	0.0	0.2	0.06	0.03	0.05	0.09	0.4	0.0	99.8	**50.6**	**99.9**
Andropogon gerardii	3.6	2.7	1.6	0.9	0.11	0.30	0.11	0.10	1.2	4.2	53.1	15.5	16.3
Anemone cylindrica	0.1	0.0	0.0	0.0	0.03	0.00	0.01	0.01	0.1	.	.	0.7	0.4
Aristida purpurea	6.1	3.8	**0.4**	**5.7**	0.23	0.25	**0.10**	**0.35**	2.5	16.2	85.4	9.6	9.0
Artemisia frigida	2.7	1.7	0.5	0.9	0.28	0.14	0.10	0.08	-1.4	2.1	17.1	2.1	17.6
Artemisia ludoviciana	0.4	0.2	0.1	0.3	0.08	0.10	0.08	0.13	-0.6	6.9	21.5	**52.8**	**0.0**
Asclepias speciosa	14.4	7.9	0.6	0.4	0.38	0.30	0.13	0.06	1.2	19.5	84.5	98.7	98.5
Bouteloua curtipendula	**7.3**	**15.4**	3.7	7.5	0.48	0.60	**0.36**	**0.59**	**11.1**	2.8	51.3	9.1	9.9
Bouteloua gracilis	**5.3**	**17.0**	3.8	6.2	0.39	0.64	0.32	0.43	**8.0**	1.9	51.6	5.2	4.2
Bouteloua hirsuta	8.0	10.1	**3.6**	**10.6**	0.35	0.41	**0.28**	**0.50**	**10.0**	1.7	58.0	5.4	12.5
Brickellia eupatorioides	**0.7**	**12.5**	**0.3**	**3.7**	0.17	0.33	0.04	0.13	1.3	0.0	82.7	79.5	64.8
Calylophus serrulatus	0.0	0.1	0.0	0.5	0.00	0.00	0.00	0.08	0.2	.	.	.	.
Cirsium undulatum	0.4	1.9	2.9	0.4	0.11	0.10	0.16	0.06	1.0	15.7	47.1	91.4	98.0
Dyssodia papposa	6.8	11.4	18.5	12.2	0.58	1.31	0.44	0.50	**51.8**	nt	nt	nt	nt
Echinacea angustifolia	**27.3**	**12.1**	5.7	7.3	0.53	0.35	0.35	0.33	5.2	6.4	38.6	**10.1**	**42.1**
Elymus elymoides	0.1	0.5	1.0	1.5	0.01	0.05	0.09	0.13	0.9	2.4	85.1	24.3	13.2
Erysimum asperum	4.8	2.2	0.5	2.5	0.18	0.13	0.06	0.19	1.5	3.7	70.9	**92.4**	**42.5**
Grindelia squarrosa	13.4	10.7	6.6	7.8	0.53	0.45	0.31	0.45	5.8	1.2	35.8	9.0	21.5
Gutierrezia sarothrae	**1.6**	**6.9**	1.6	5.7	0.09	0.20	0.13	0.23	2.2	0.4	39.7	1.4	10.9
Helianthus annuus	18.0	10.3	10.7	4.7	**4.88**	**2.20**	0.23	0.25	1.5	nt	nt	.	.
Hesperostipa comata	2.4	0.7	1.2	0.0	0.11	0.06	0.13	0.01	0.1	7.3	70.6	19.6	47.0
Heterotheca villosa	**2.1**	**12.1**	**0.1**	**4.1**	0.10	0.28	0.03	0.10	0.8	3.3	57.9	48.5	29.9
Ipomoea leptophylla	0.2	0.1	0.0	0.0	0.03	0.03	0.03	0.00	0.1	97.2	.	.	.
Liatris punctata	**0.5**	**9.5**	0.2	1.1	0.08	0.38	0.05	0.18	1.1	21.0	91.5	52.5	84.3

Species	2005 Adjusted Seedling # (%)*		2006 Adjusted Seedling # (%)*		2005 Seedling Cover (%)*		2006 Seedling Cover (%)*		2006 Mix – Control Seedling Number †	2005 Growing Season Mortality (%)	2005-06 Winter Mortality (%)	2006 Growing Season Mortality (%)*	
	F	S	F	S	F	S	F	S				F	S
Monarda fistulosa	0.4	0.0	0.4	0.1	0.05	0.00	0.04	0.04	0.4	.	.	26.5	58.9
Nassella viridula	**11.5**	**5.6**	6.2	4.6	0.55	0.48	0.49	0.42	4.6	4.0	49.8	13.9	8.9
Oligoneuron rigidum	2.8	3.1	2.6	2.2	0.23	0.28	0.20	0.15	1.6	0.7	94.7	79.0	86.6
Onosmodium molle	0.2	0.1	0.5	3.2	0.16	0.03	0.10	0.19	1.6	0.1	87.7	95.0	72.4
Penstemon grandiflorus	**8.8**	**1.1**	2.8	3.6	0.28	0.07	0.19	0.17	1.2	5.4	20.0	**25.8**	**59.4**
Plantago patagonica	0.1	0.6	0.4	0.1	0.03	0.06	0.04	0.01	0.5	45.3	99.7	97.8	99.9
Psoralidium tenuiflorum	8.6	7.2	6.3	2.6	0.34	0.50	**0.58**	**0.19**	1.5	46.0	15.2	85.6	97.8
Ratibida columnifera	5.3	5.0	1.3	0.2	0.78	0.55	0.18	0.10	1.2	10.1	29.6	21.7	66.5
Schizachyrium scoparium	5.3	4.0	2.6	4.6	0.38	0.36	0.29	0.37	**7.9**	1.3	72.8	21.8	9.6
Solidago missouriensis	0.0	0.1	0.0	0.0	0.00	0.13	0.00	0.04	0.1	.	.	.	.
Solidago nemoralis	0.2	0.0	1.4	0.0	0.08	0.01	0.07	0.01	**1.2**	.	.	94.7	100.0
Sporobolus cryptandrus	3.2	5.9	5.6	7.1	0.38	0.39	0.51	0.51	6.6	1.9	40.2	16.1	18.5
Symphyotrichum ericoides	2.9	6.7	2.7	3.0	0.28	0.39	0.34	0.34	5.0	2.2	59.7	37.4	49.1
Verbena bracteata	**15.7**	**33.2**	4.1	3.3	**1.15**	**4.30**	0.23	0.25	1.5	3.4	61.0	70.0	98.2
Verbena stricta	8.7	9.5	2.7	2.5	0.49	0.43	0.16	0.21	-0.2	2.7	42.2	32.4	44.9

*Values in **bold** indicate a significant ($P < 0.05$) difference between fall- and spring-planted plots for that species.

†Values in **bold** indicate that the value is significantly ($P < 0.05$) greater than 0.

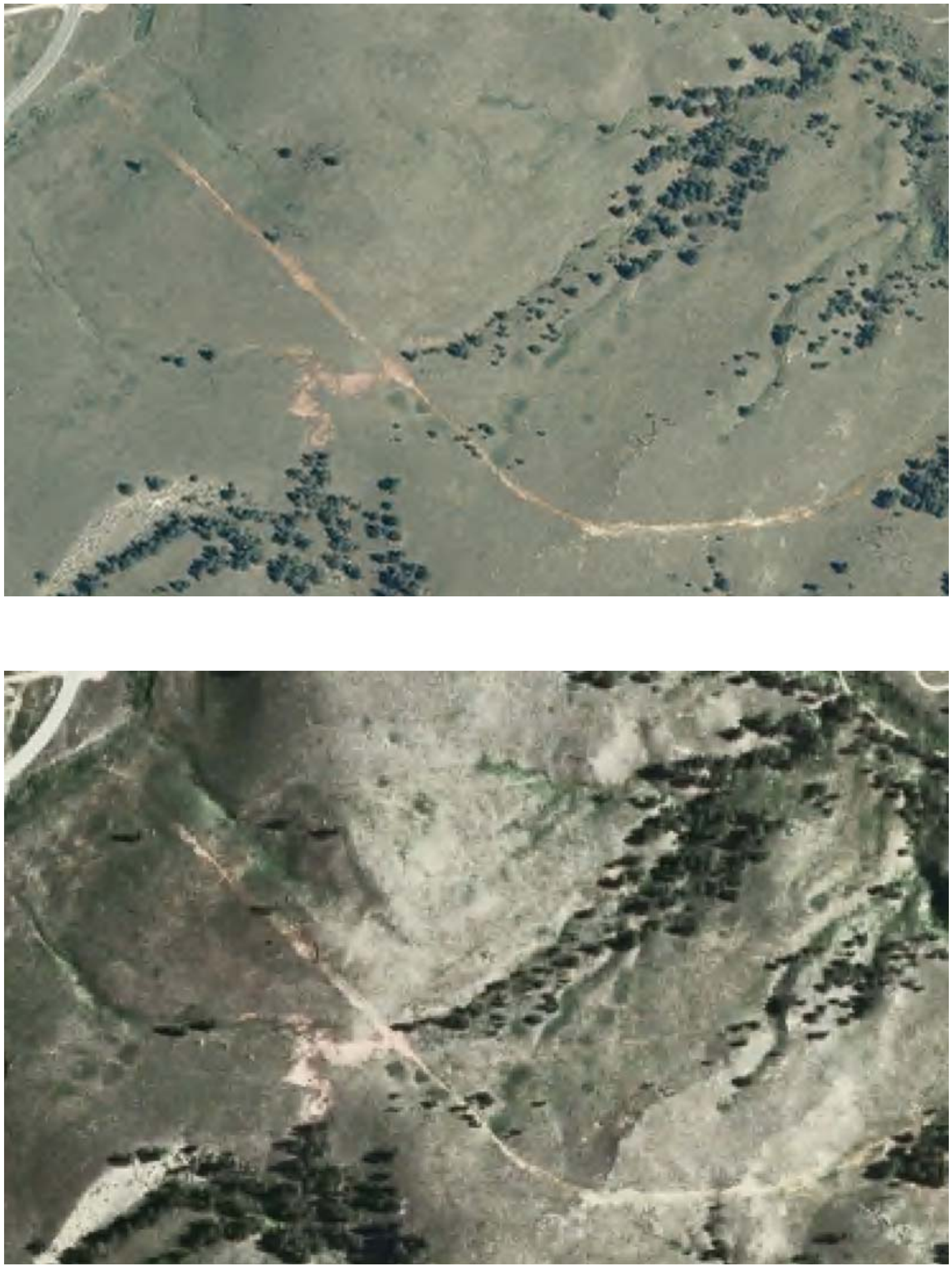


Figure 1. Aerial photographs of water line in 2004 (above) and 2006 (below). The area shown is south and east of the visitor center, where transects 1-8 were located.

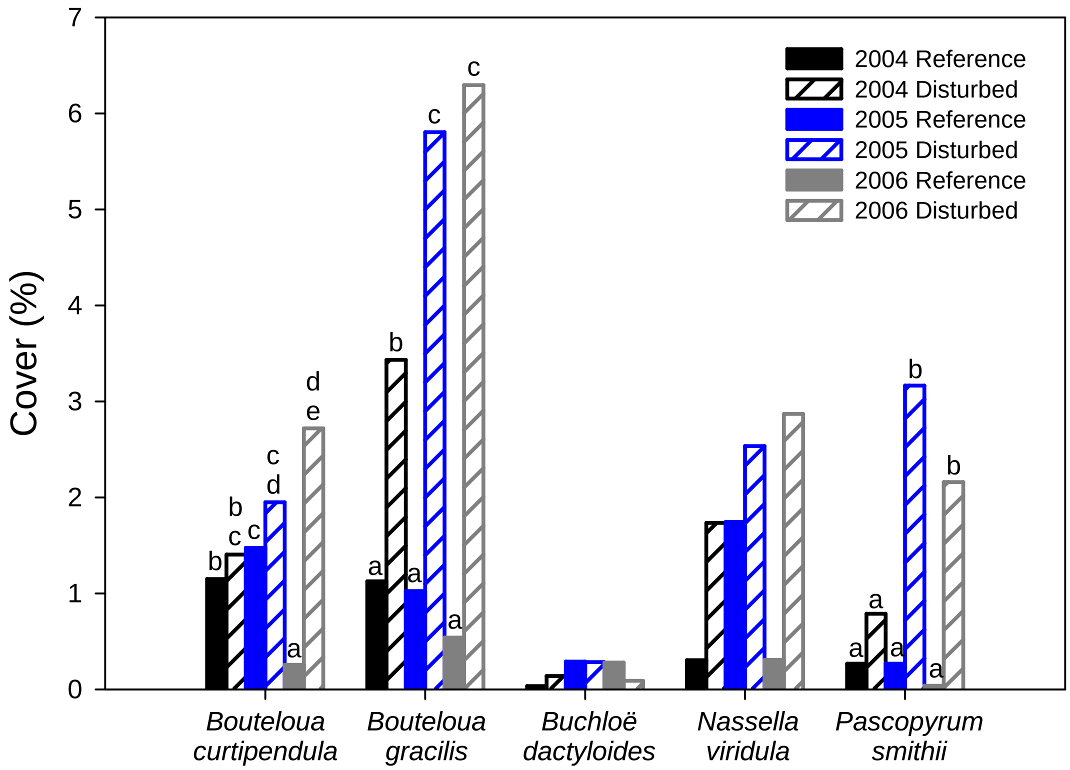


Figure 2. Least squares means of foliar cover of five grass species planted in the water line revegetation project, by year of data collection and vegetation type. Bars within a species sharing a lowercase letter are not significantly different from each other ($P > 0.05$). Species with no letters above bars had no significant vegetation type x year interaction (see Table 3).

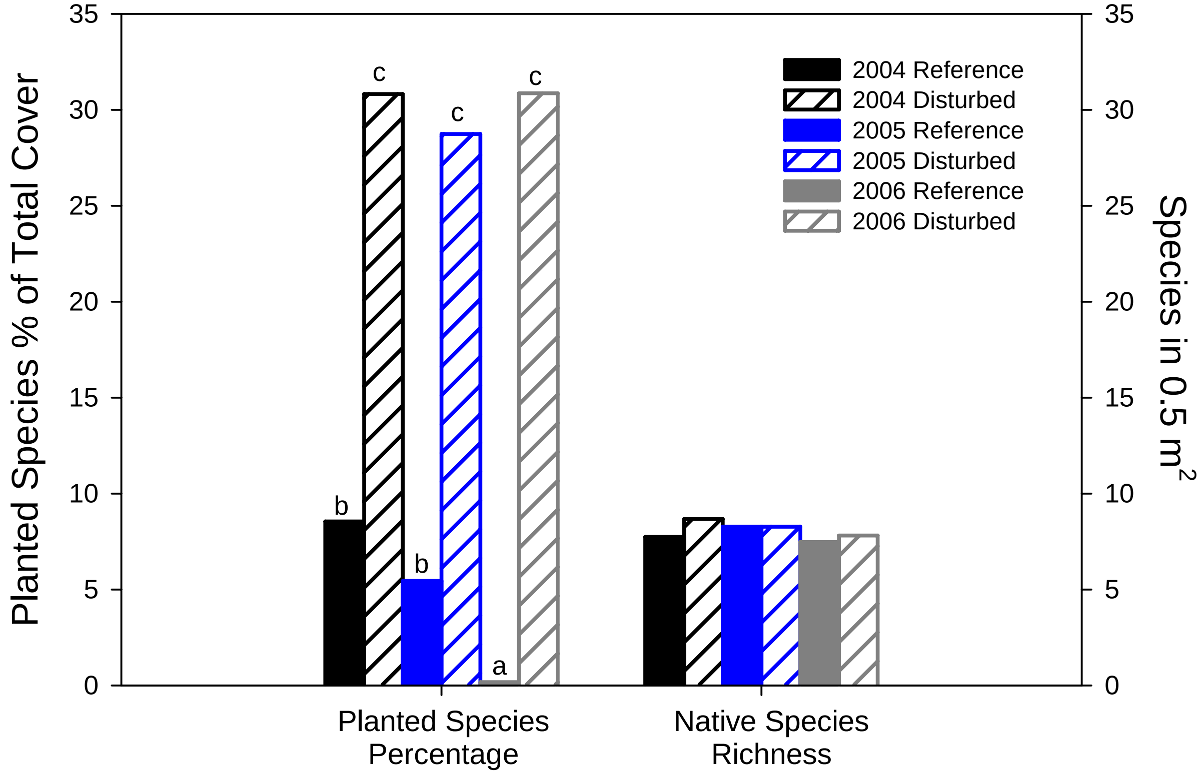


Figure 3. Least squares means of the percentage of total plant cover comprised of the five species planted (left axis) and native species richness (right axis), in the water line revegetation project by year of data collection and vegetation type. Bars within a variable sharing a lowercase letter are not significantly different from each other ($P > 0.05$). Native species richness had no significant vegetation type x year interaction (see Table 3).

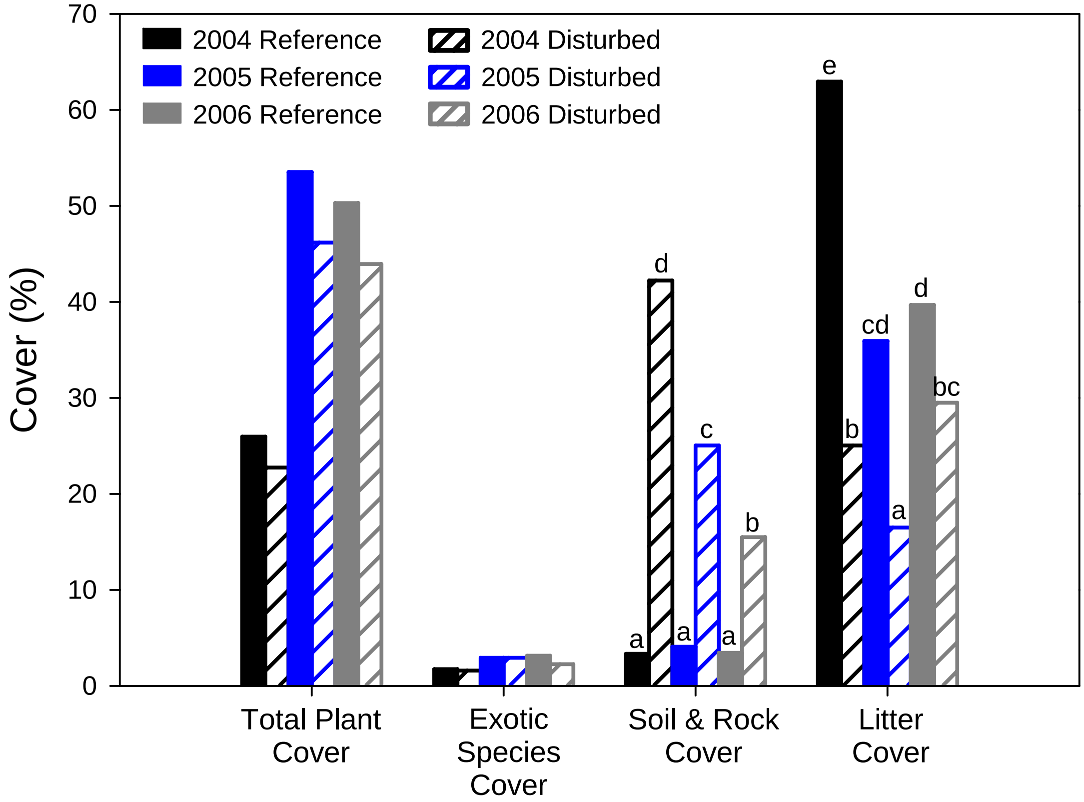


Figure 4. Least squares means of plant and ground cover in the water line revegetation project by year of data collection and vegetation type. Bars within a variable sharing a lowercase letter are not significantly different from each other ($P > 0.05$). Variables with no letters had no significant vegetation type x year interaction (see Table 3).

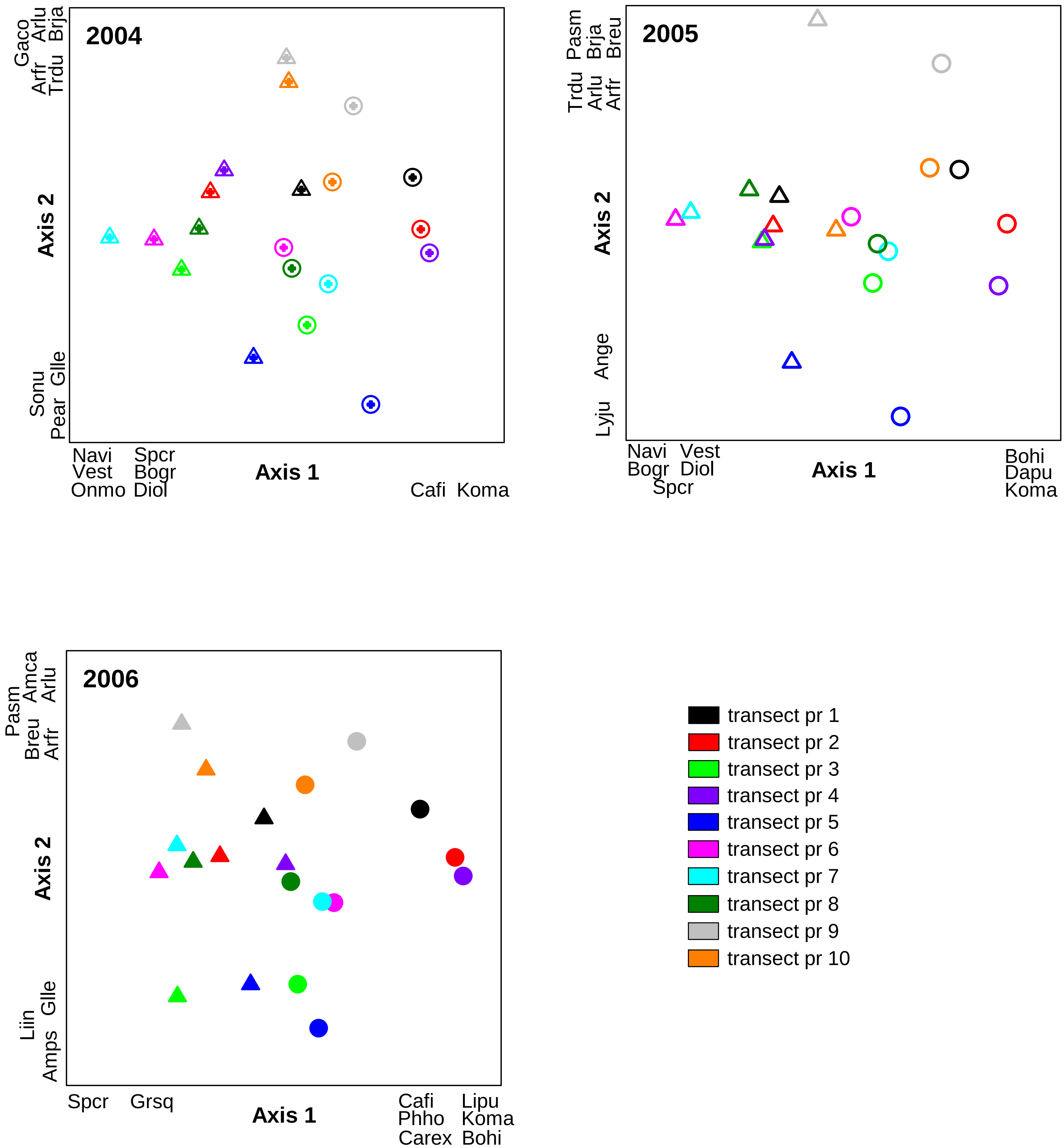


Figure 5. PCA plots of transects based on species' importance values for each year separately. Colors indicate a transect pair, with triangles representing the disturbed transect and circles representing the undisturbed transect. Species correlated to axes are indicated by species abbreviations (two letters each of genus and species), with the species most closely related to the axis positioned closest to the axis. See Appendix 1 for full species names and common names.

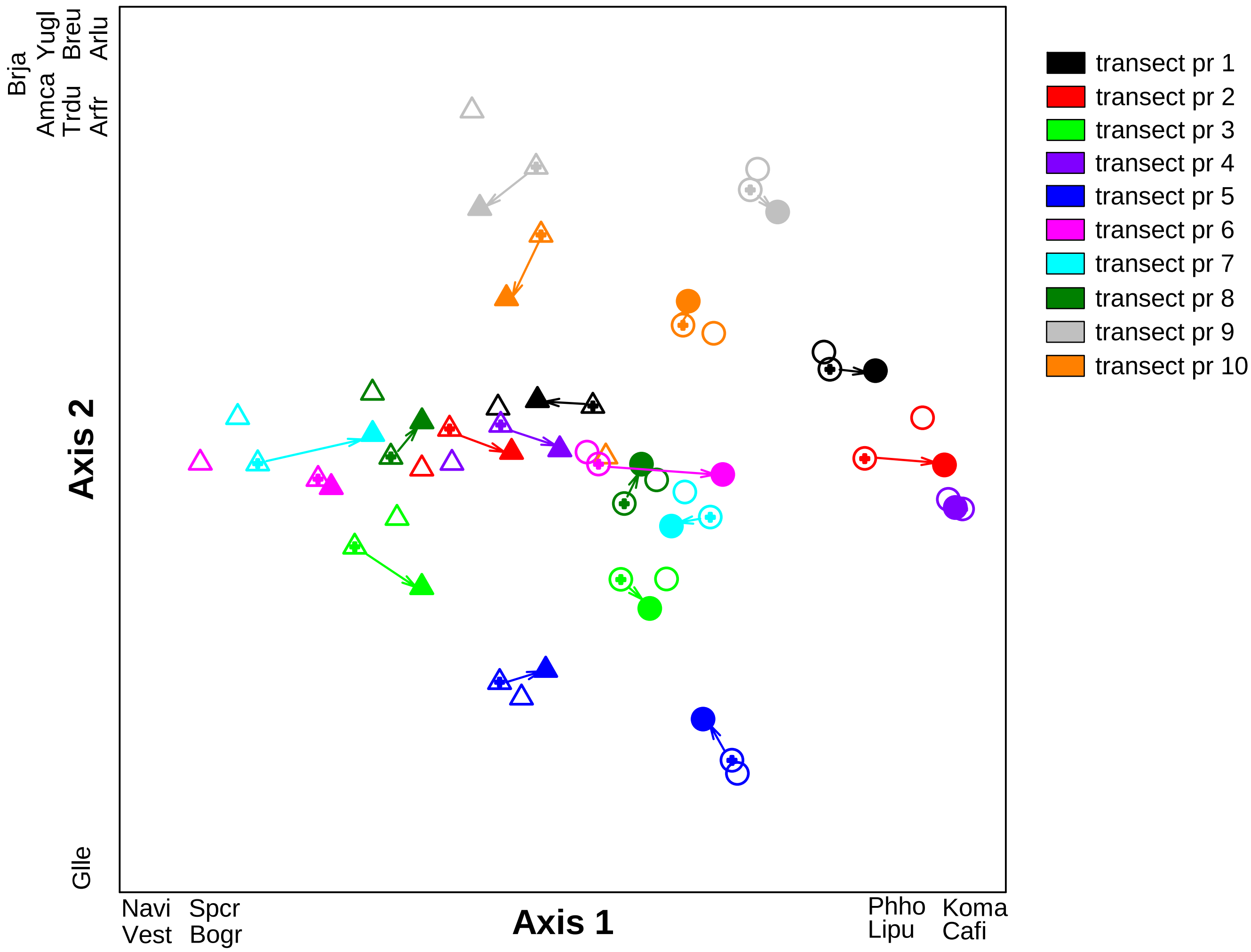


Figure 6. PCA plot of transects based on species' importance values, through time (2004 = cross-haired symbols; 2005 = open symbols; 2006 = filled symbols). Colors indicate a transect pairs, with triangles representing the disturbed transect and circles representing the reference transect. Arrows indicate changes from 2004 to 2006 for each of these. Species correlated to axes are indicated by species abbreviations (two letters each of genus and species), with the species most closely related to the axis positioned closest to the axis. See Appendix 1 for full species names and common names.

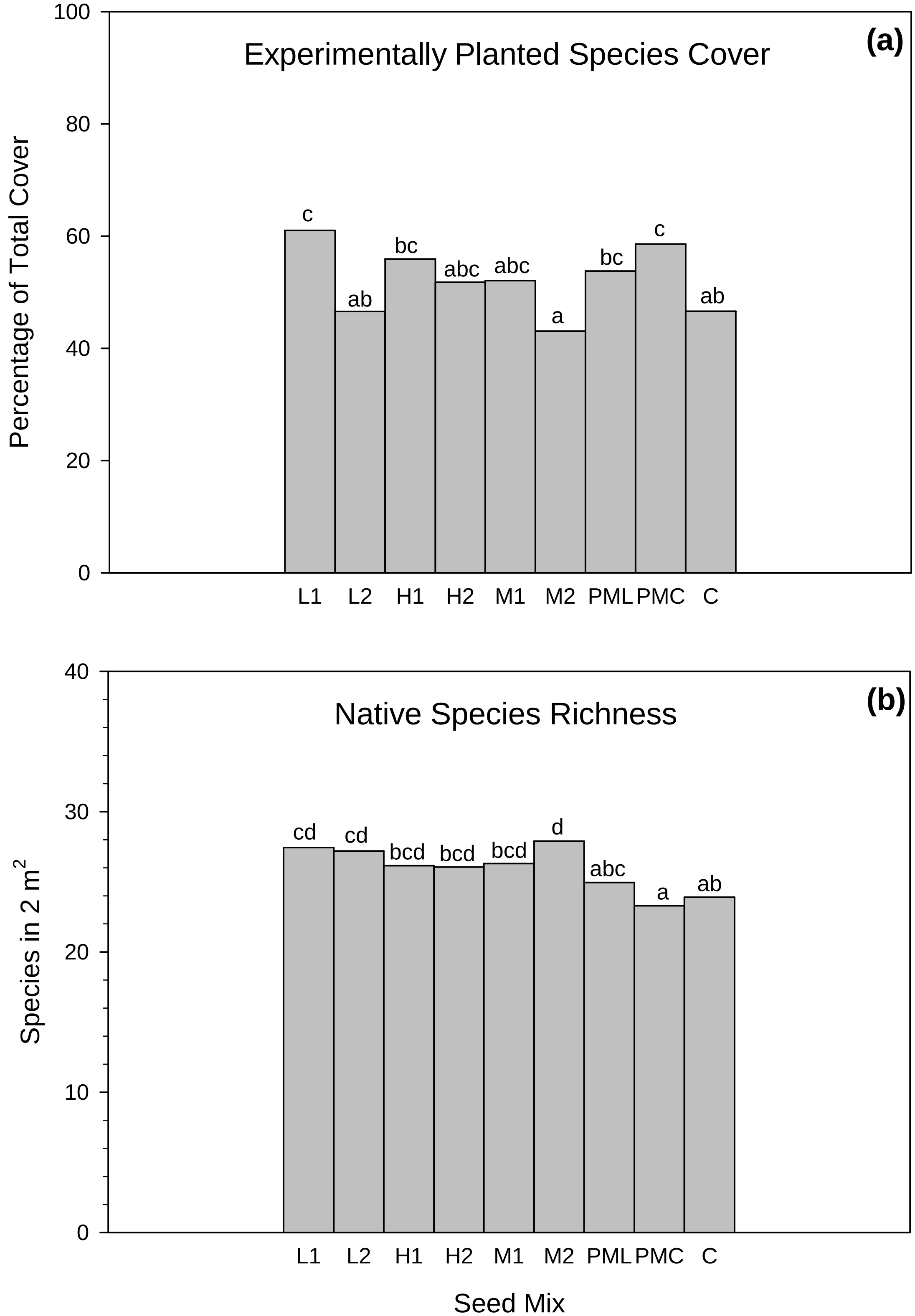
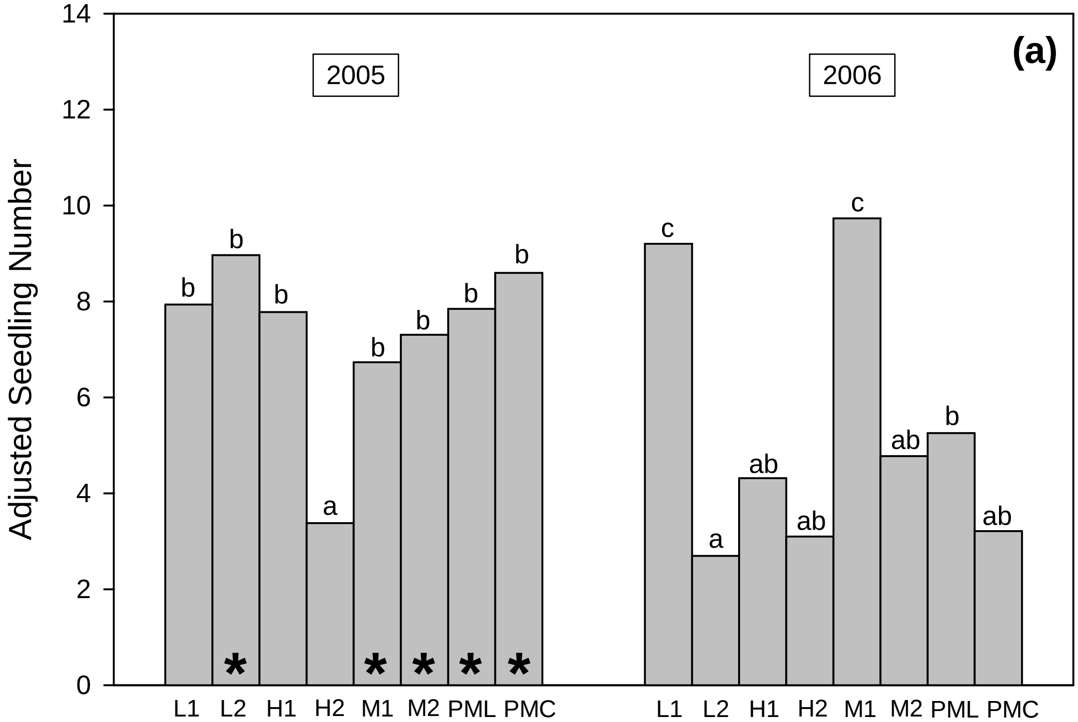


Figure 7. Least-squares means of (a) experimentally planted species cover, as a proportion of total cover, and (b) native species richness by seed mix in experimental plots. Mixes sharing a lower-case letter are not significantly (P <0.10) different from each other. Means were back-transformed when necessary.



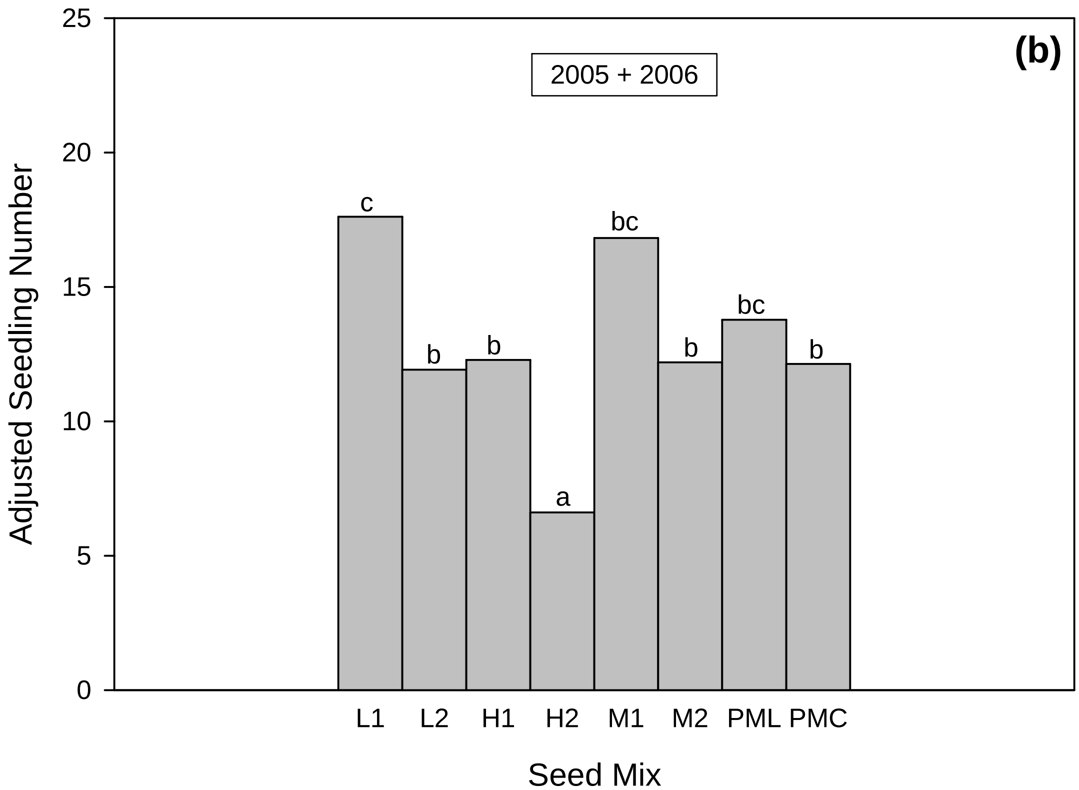
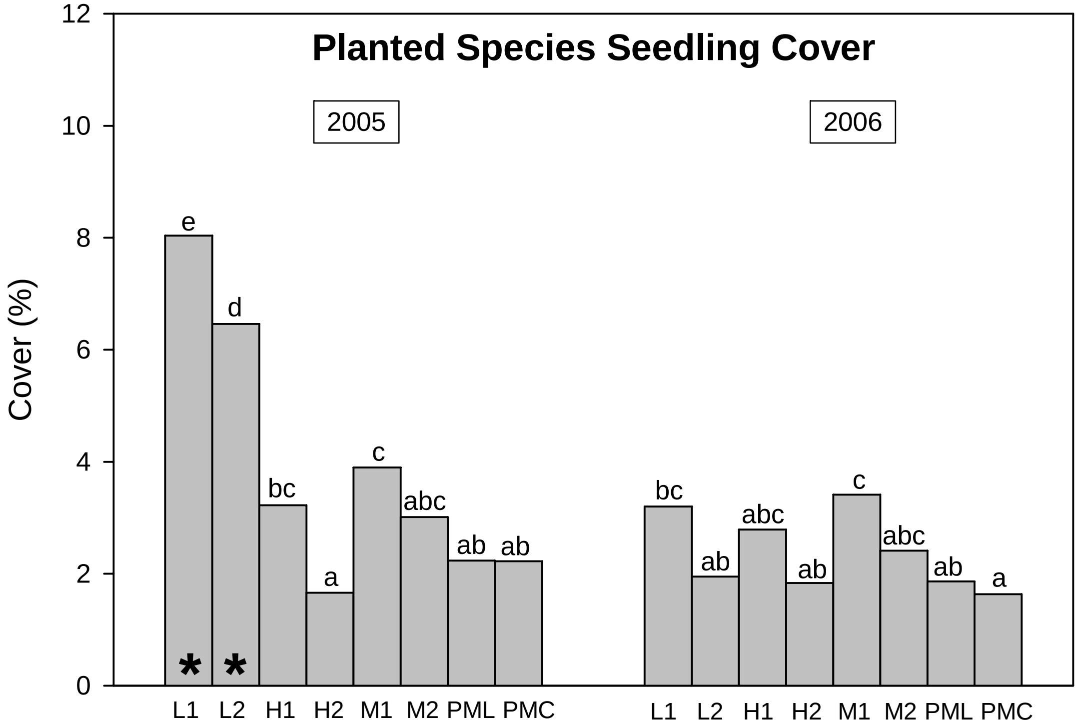


Figure 8. Seed mix least-squares means of adjusted seedling number (number of seedlings as a percentage of seeds planted in the area sampled) for (a) 2005 and 2006 separately and (b) totalled over the two years. Mixes sharing a lower-case letter within a group of bars are not significantly (P <0.10) different from each other. In (a), an asterisk at the base of a bar indicates a significant difference in adjusted seedling number for that mix between 2005 and 2006. Means were back-transformed.



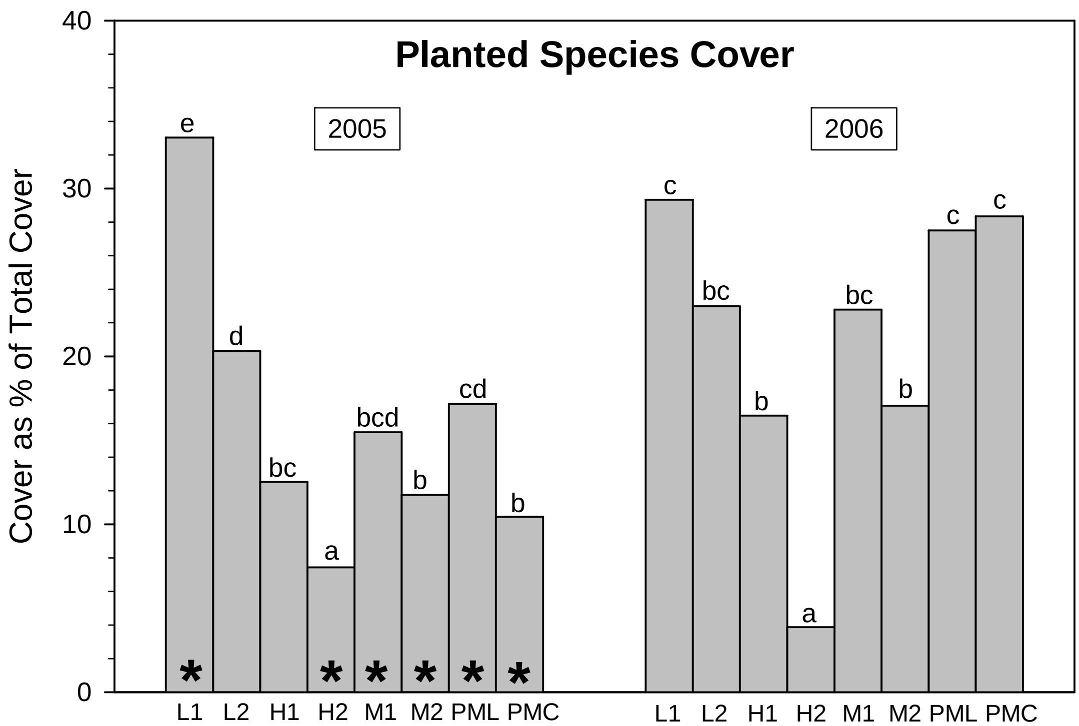


Figure 9. Seed mix least-squares means of (a) seedling foliar cover of species planted in the mix and (b) total foliar cover of species planted in the mix as a percentage of total plant cover. Mixes sharing a lower-case letter within a group of bars are not significantly (*P* <0.10) different from each other. An asterisk at the base of a bar indicates a significant difference between 2005 and 2006 for that mix . Means were back-transformed.

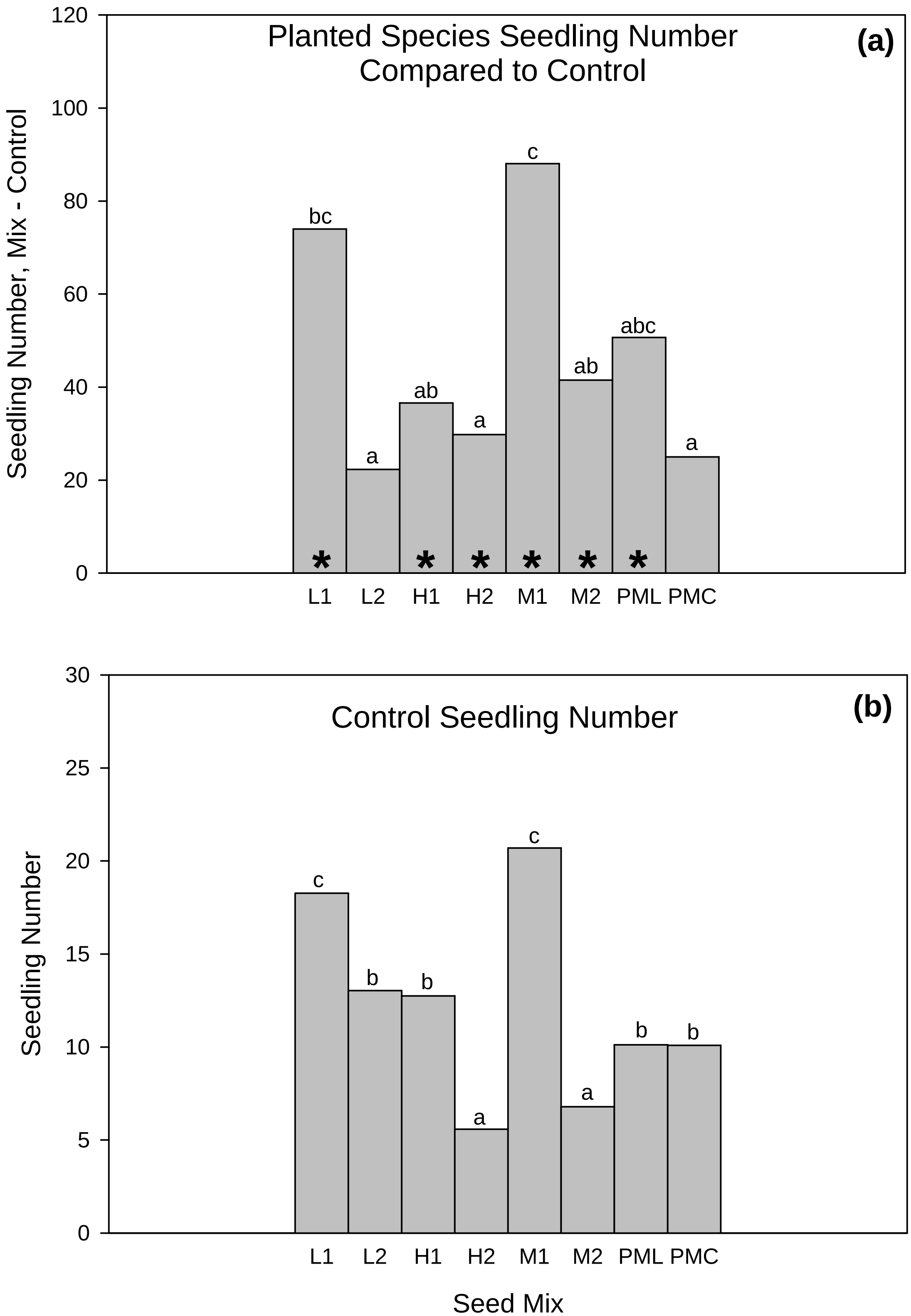


Figure 10. 2006 seed mix least-squares means of (a) difference in planted species' seedling number between the mix and the control in the same block and (b) the control's seedling number for the mix's species. Mixes sharing a lower-case letter are not significantly (P <0.10) different from each other. In (a), an asterisk at the base of a bar indicates that the value is significantly (P <0.10) greater than 0.

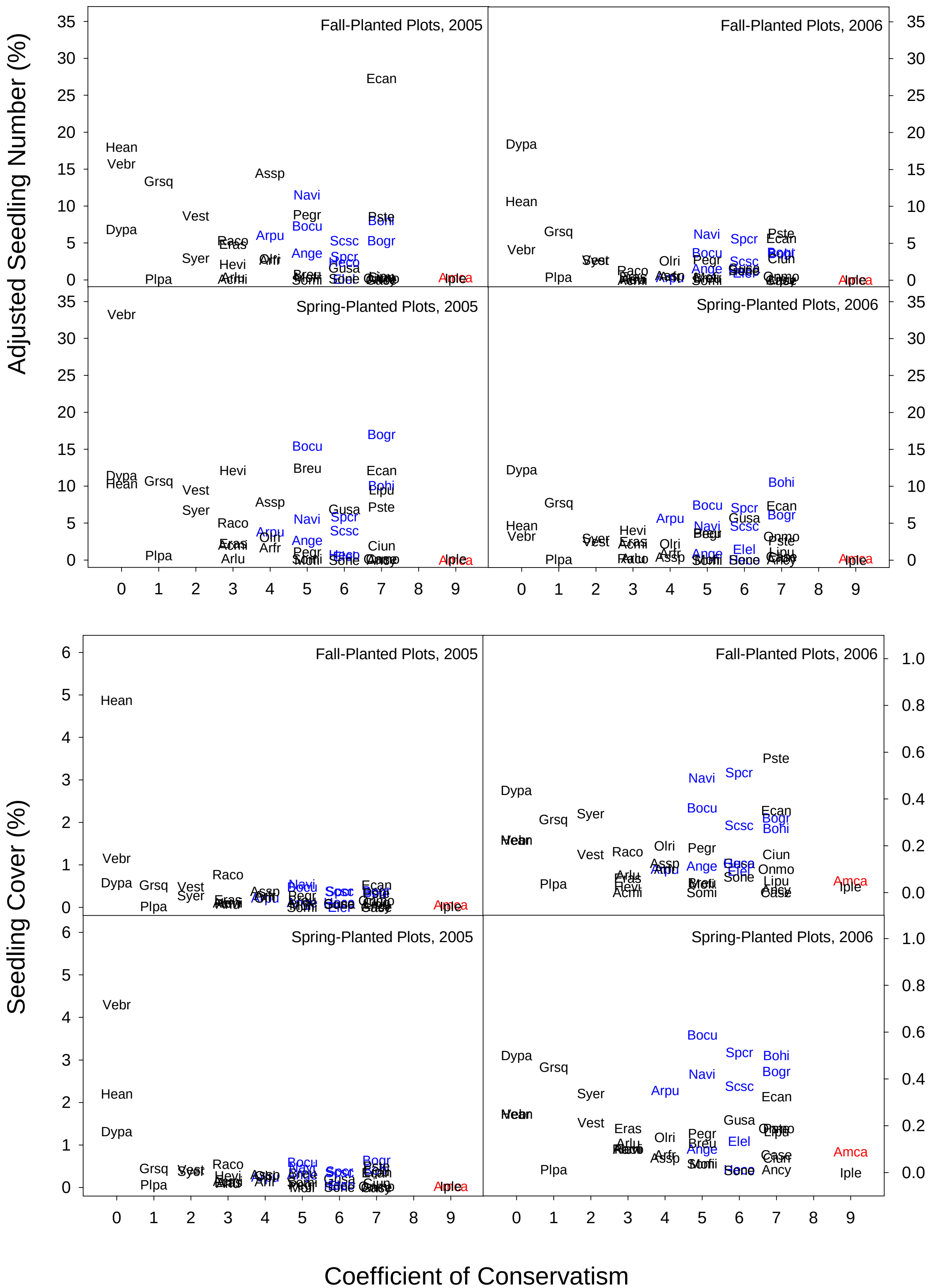


Figure 11. Adjusted seedling number (top) and seedling cover (bottom) by C-value, planting season, and year of data collection for 40 species planted in experimental plots. Symbols are the first two letters of genus and species. Black symbols are forbs, blue symbols are grasses, and red sybols are shrubs. Note difference in y-axis scales for 2005 (left) and 2006 (right) for seedling cover.

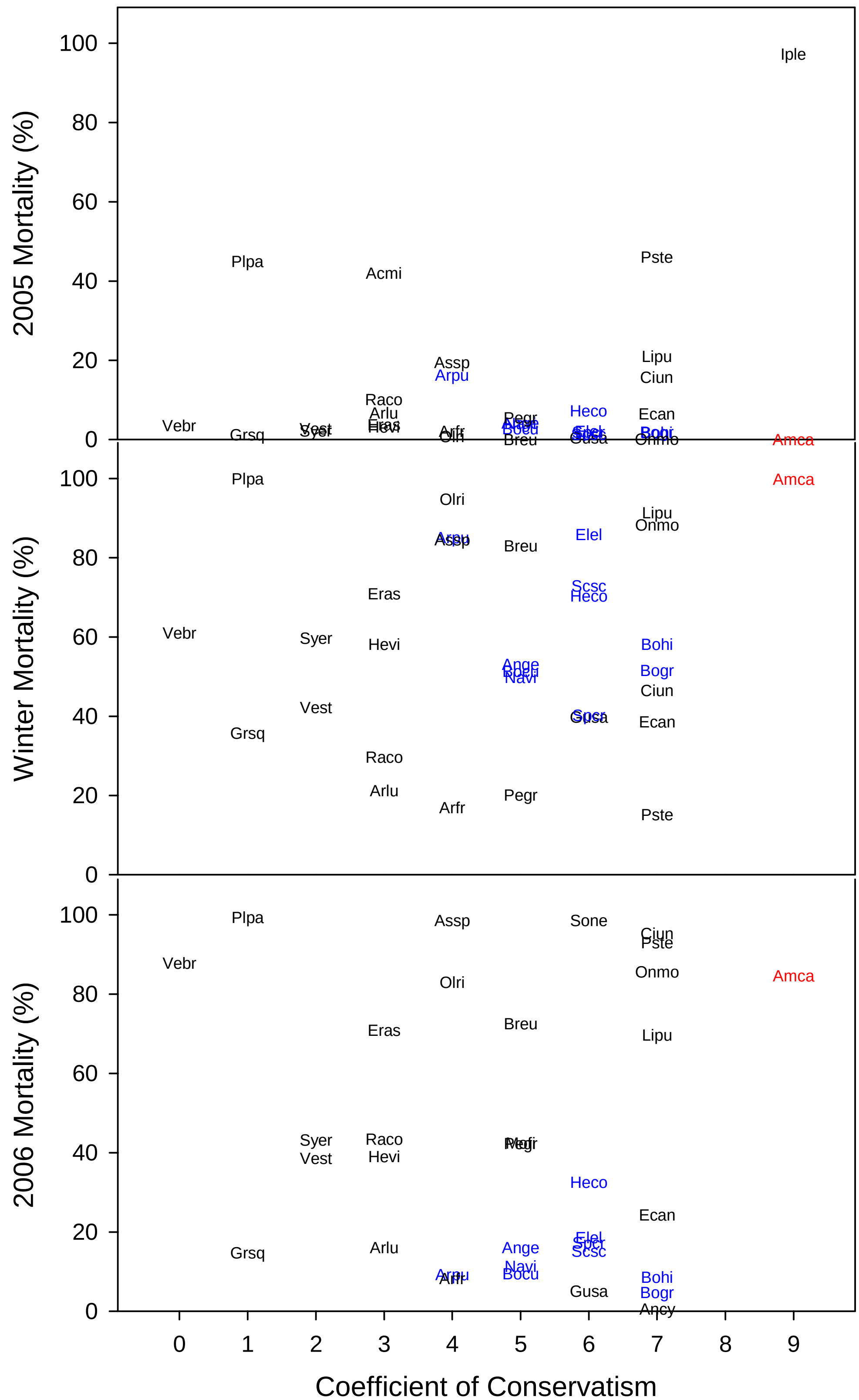


Figure 12. Seedling mortality during the 2005 growing season (top), over winter (middle), and during the 2006 growing season (bottom), by C-value, for species planted in experimental plots. Symbols are the first two letters of genus and species. Black symbols are forbs, blue symbols are grasses, and red symbols are shrubs.

Appendix 1. Basic information on species mentioned in text of report.

Species	Species name in *Flora of the Great Plains* (if different)	Common Name	Origin	Growth Form	Coefficient of Conservatism	Planted in Mix(es)
Achillea millefolium		common yarrow	native	forb	3	L2
Amorpha canescens		lead plant	native	shrub	9	H1, M1
Ambrosia psilostachya		western ragweed	native	forb	2	--
Andropogon gerardii		big bluestem	native	grass	5	H1, H2
Anemone cylindrica		thimbleweed	native	forb	7	H2, M2
Aristida purpurea		red three-awn	native	grass	4	L1
Artemisia frigida		fringed sagewort	native	subshrub	4	L1, M1
Artemisia ludoviciana		white sage; man sage	native	forb	3	L1, M1
Asclepias speciosa		showy milkweed	native	forb	4	L2, M2
Bouteloua curtipendula		sideoats grama	native	grass	5	L1, M1, L2, M2, PML, PMC
Bouteloua gracilis		blue grama	native	grass	7	H1, M1, PML, PMC
Bouteloua hirsuta		hairy grama	native	grass	7	H2, M2
Brickellia eupatorioides	*Kuhnia eupatorioides*	false boneset	native	forb	5	L1, H1, L2
Bromus japonicus		Japanese brome	exotic	grass	-	--
Bromus tectorum		cheat grass	exotic	grass	-	--
Buchloë dactyloides		buffalo grass	native	grass	4	--
Calylophus serrulatus		yellow evening primrose	native	subshrub	7	H1, M1
Carex filifolia		threadleaf sedge	native	sedge	7	--

Species	Species name in *Flora of the Great Plains* (if different)	Common Name	Origin	Growth Form	Coefficient of Conservatism	Planted in Mix(es)
Cirsium undulatum		wavyleaf thistle	native	forb	7	H2, M2
Dichanthelium oligosanthes		Scribner dichanthelium	native	grass	6	--
Dyssodia papposa		fetid marigold	native	forb	0	L1, M1
Echinacea angustifolia		purple coneflower	native	forb	7	H1
Elymus elymoides		squirreltail	native	grass	6	H1, M1, H2
Erysimum asperum		western wallflower	native	forb	3	L2, M2
Gaura coccinea		scarlet gaura	native	forb	4	--
Glycyrrhiza lepidota		wild licorice	native	forb	2	L1
Grindelia squarrosa		curlycup gumweed	native	forb	1	L1, M1
Gutierrezia sarothrae		snakeweed	native	forb	6	H1, H2
Helianthus annuus		plains sunflower	native	forb	0	L1
Hesperostipa comata	*Stipa comata*	needle-and-thread	native	grass	6	H2, M2
Heterotheca villosa	*Chrysopsis villosa*	hairy false golden-aster	native	forb	3	L1
Ipomoea leptophylla		bush morning-glory	native	forb	9	H1, H2
Koeleria macrantha	*Koeleria pyramidata*	Junegrass	native	grass	7	--
Liatris punctata		dotted blazing star	native	forb	7	H2
Lithospermum incisum		narrowleaf puccoon	native	forb	7	--
Marrubium vulgare		white horehound	exotic	forb	-	--
Medicago lupulina		black medic	exotic	forb	-	--
Melilotus officinalis		yellow sweetclover	exotic	forb	-	--
Monarda fistulosa		wild bergamot	native	forb	5	L2, H2

Species	Species name in *Flora of the Great Plains* (if different)	Common Name	Origin	Growth Form	Coefficient of Conservatism	Planted in Mix(es)
Muhlenbergia cuspidata		plains muhly	native	grass	8	--
Nassella viridula	*Stipa viridula*	green needlegrass	native	grass	5	L1, H1, M1, PML, PMC
Oligoneuron rigidum	*Solidago rigida*	stiff goldenrod	native	forb	4	L1, M1
Onosmodium molle		false gromwell	native	forb	7	H2, M2
Pascopyrum smithii	*Agropyron smithii*	western wheatgrass	native	grass	4	L2, M2, PML, PMC
Penstemon grandiflorus		large beardtongue	native	forb	5	L1, M1, L2
Phlox hoodii		Hood's phlox	native	forb	6	--
Plantago patagonica		woolly plantain; Indian wheat	native	forb	1	L2, M2
Poa pratensis		Kentucky bluegrass	exotic	grass	-	--
Psoralidium tenuiflorum	*Psoralea tenuiflora*	slimflower scurfpea	native	forb	7	H1, M1
Ratibida columnifera		prairie coneflower	native	forb	3	L2
Rosa arkansana		prairie wild rose	native	shrub	3	L1
Rhus trilobata	*Rhus aromatica* var. *trilobata*	skunkbrush sumac	native	shrub	7	--
Schizachyrium scoparium	*Andropogon scoparius*	little bluestem	native	grass	6	H1, M1, PML, PMC
Solidago missouriensis		prairie goldenrod	native	forb	5	H1, H2
Solidago nemoralis		gray goldenrod	native	forb	6	H1, H2, M2
Sorghastrum nutans		Indian grass	native	grass	6	--
Sporobolus cryptandrus		sand dropseed	native	forb	6	H2, M2

Species	Species name in *Flora of the Great Plains* (if different)	Common Name	Origin	Growth Form	Coefficient of Conservatism	Planted in Mix(es)
Symphoricarpos occidentalis		western snowberry	native	shrub	3	L2, M2
Symphyotrichum ericoides	*Aster ericoides*	heath aster	native	forb	2	L2, M2
Toxicodendron rydbergii		poison ivy	native	shrub	3	--
Verbena bracteata		prostrate vervain	native	forb	0	L2
Verbena stricta		hoary vervain	native	forb	2	L2